FRR 153

SYMPOSIUM PROCEEDINGS

"APPLICATIONS IN A CHANGING WORLD"

GIS 91

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Vancouver
Canada

GIS'91, an International Symposium on Geographic Information Systems, is sponsored by Forestry Canada under the Canada-British Columbia Forest Resource Development Agreement, with major participation by the Province of British Columbia, Reid, Collins and Associates and Digital Mapping Group Ltd.

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Welcome Messages

Applications in a Changing World, the theme for the GIS'91 Symposium, is an appropriate description of the three major challenges faced by Canada's forest sector: increasing international competition, competing demands for the forest resource and public demands for more environmentally neutral forest management.

Forestry Canada is striving to respond to these challenges, mindful of the principle of sustainable development, which necessitates a long-term perspective and considers both economic and environmental variables in the decision - making process. Sustainable development encompasses sustained timber yield as well as non-timber benefits such as recreation, wildlife, tourism and genetic diversity.

GIS forestry applications complement this response by providing a tool to improve forest resource management planning, and allowing for informed resolution of resource - use conflicts.

GIS'91 continues the series of high - quality symposia that have been held in Western Canada. I am proud to note that Forestry Canada has played a major role in delivering this series, and we look forward to continued involvement in developing both the technology and business aspects of geographic information systems.

Honourable Frank Oberle
Minister of Forestry

British Columbia's prosperity is based on a wealth of natural resources. Sustaining and developing this legacy has challenged us to become more innovative in resource management. Geographic Information Systems (GIS) help us rise to this challenge.

The benefits for British Columbia are twofold. While increasing our ability to more effectively manage our vital resources, we have also developed a new high-tech industry in land information management that can be applied worldwide.

I commend both organizers and participants of GIS'91 for their vision and commitment in developing new and effective tools to meet the challenge of a changing physical world.

Honourable Bud Smith, Q.C.
Minister of Regional and Economic Development

As Geographic Information Systems (GIS) and their benefits in land and resource management become better understood by the public and a mainstay of the high technology sector, we can envision a future where this powerful tool will become as commonplace in the provincial government as the telephone.

The Ministry of Crown Lands has taken a lead role in directing the development and implementation of GIS across government. As a guiding philosophy, the ministry maintains that not only the tools, but the data itself must support our common efforts in land information management. This approach requires certain basic data to be readily available in order to avoid costly duplication of effort while ensuring that all users are operating with common points of reference. Our Terrain Resource Information Management (TRIM) program provides such a common geographic base for all GIS applications.

Along these same lines, the Ministry is leading the Corporate Land Information Strategic Plan (CLISP), a framework to ensure cross-sectoral access to data held by all ministries in support of GIS initiatives. Not only is this approach to corporate data management visionary, in that it is designed to take advantage of the technology's long-range benefits, it also ensures a continued partnership with the private sector by utilizing the expertise and enthusiasm of existing companies to build this vision today.

Honourable Dave Parker
Minister of Crown Lands

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Forest Management - Wood Supply/Harvesting
International Forestry Applications
Engineering and Industrial Applications
Corporate GIS

Environmental Issues and GIS

Old Growth Forests
Multiple Use
Integrated Use
Climate Change

GIS Techniques

System Architecture
Client Server Technology
Spatial Data
Concepts and Issues
Remote Sensing and Video
Integrated Database Management

Special Interest Group, BC Crown Lands

Ministry of Crown Lands - New Initiatives

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Legal Issues and GIS

GIS Education

Education and Training

Municipal Applications

Data Standards and Conversions
Municipal Case Studies
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Where is the Technology Leading Us?

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Abstract

With GIS technology now about 25 years old, it is appropriate to consider where GIS use may be leading us, with special reference to natural resource management uses and considering forest management in particular. After beginning with a consideration of where GIS technology is going, and with mention of several important related technologies, the paper considers the range of problems and of possible immediate futures for natural resource management generally, and for forest management in particular. The role of GIS in natural resource management is taken up next. Some comments on who determines where GIS technology will go in the future are offered. The paper concludes with a consideration of where GIS technology may lead natural resource management in the next decade and just after the turn of the century.

Introduction

The first uses of automated means for processing geographically referenced data occurred about 25 years ago.

With the extremely rapid recent growth in the use of this technology in many fields, including forestry and natural resource management, it is appropriate to consider the implications of its use, and in particular, where the technology may be leading its users in the foreseeable future, perhaps ten years from now, and beyond.

This paper considers the future of the technology itself, of GIS applications to natural resource management, and of forest management as an example of a particular area of natural resource management which uses GIS extensively.

Where GIS Technology Is Going

The most important fact to bear in mind about GIS and related technologies is the rapid growth which is occurring in their use. It is likely that by about the year 2000 there will be a million users of GIS technology. This assumes annual growth rates of between 25 and 40 per cent; the field has been experiencing such rates for a number of years.

The continuing rapid developments in processing speed, storage density, wide-band communications technology and other areas of hardware technology guarantee that the costs to acquire GIS capabilities will continue to fall and system performance will continue to rise.

GIS technology provides the means for integrating many kinds of spatial data, either through conversion, capture from existing hardcopy products, or referencing other kinds of data to a map. These sorts of integration capabilities will increase and GISs will be able to bring together increasingly diverse kinds of spatially referenced data from an ever wider variety of source media.

GIS technology will also continue to grow easier to learn and to use because additional efforts and computer power will be devoted to the user interface and to making all kinds of GIS functions easier to do.

Actual testing and the growing acceptance of GIS technology both indicate that GIS technology is becoming more reliable and more cost effective. As a result, governments and large corporations are investing heavily in acquiring the technology. Once acquired, the use of the technology usually expands, sometimes very rapidly.

With gradual improvements occurring in scanning and related technologies, and greater understanding of how to automate previously existing data, larger investments are being made in the creation of digital databases for GIS use. This makes further investments ever easier to justify, so that rapid increases in the size and number of digital databases can be expected in the years just ahead, as international events and budgets permit.

In the years just ahead, global GIS databases of various kinds are going to become available, probably in a few years, on global networks.

If numbers of students are considered, training programs in GIS technology are growing even more rapidly than the field itself. This means that there will be many more people, with at least basic knowledge of GIS, available for employment in the next few years than has been the case in the past. Related to this growth is an equally rapid growth in the technical literature in the field, with many new publications now occurring in book form and many new introductory and intermediate level textbooks just now becoming available.

As the number of people in the GIS field increases, the number of firms offering specialized consulting, contract programming, analysis, data capture, rent-a-tech, and other GIS services will continue to expand.

All of these developments are producing a rising interest in GIS technology and increased optimism about what it may be capable of doing for its users.

Related Technologies

It is also important to recognize that GIS technology is closely allied with various other technologies, such as remote sensing and other data capture technologies, communications, image processing, and the like. So if we are trying to see where the technology is leading us, we also have to take these other technologies into account.

Because most of these technologies are considerably more mature than is GIS, less profound short term change is likely to occur in them, but as they advance, so too, will GIS, and some important developments in these related areas can be anticipated in the middle and longer term.

Where Natural Resource Management May be Going

It is not this author's aim or function to predict the future of natural resource management generally or of forest management in particular. Such an effort is obviously outside of his competence. But in order to indicate where GIS technology may be leading users in the natural resource managment fields, its necessary to speculate about the possible range of developments in these fields and how GIS technology may relate to them.

Forests present, in some ways, a critical, even a paradoxical case of natural resource management efforts because they are simultaneously one of the most carefully conserved of natural resources as well as one of the most extensively used as a source of goods for sale.

Forest management is especially important because forests, unlike some other natural resources, are a potentially renewable resource. But forest management policies and practices which a few decades ago were generally well accepted are becoming controversial today.

As a result, forests, which a few decades ago represented an almost idyllic remoteness in the minds of most people around the world, are now becoming frontlines in economic, international trade, environmental, political and other types of controversies.

The interrelations between forests and such global issues as loss of habitat and species diversity, acid precipitation, and possible global warming through rising levels of carbon dioxide, are drawing increased attention to the importance of the world's forests. Managed as wilderness, recreational resources, resorts, watersheds, preserves, parks, greenbelts, shelter belts, or related kinds of purposes, forests are attracting the attention of rapidly growing numbers of people around the world. Managed for sawn timber, a growing variety of forest products, paper products, fuel wood, or other commercial purposes, forests continue to engage the attention of most national and sub-national governments and of many organizations in industry and commerce.

International commerce in timber, forest products and paper is, if anything, more important and more complex today than previously, while international efforts to preserve rainforests, old growth and ancient forests are growing in intensity.

In many less developed countries forests represent, often simultaneously, the chief source of fuel, a major national resource, a major export, and a major impediment to the expansion of agriculture. The removal of forests often leads to rapid loss of soil fertility, to rapid erosion, to desertification, and, ultimately, to a worsened human habitability and chance of human survival.

It is inevitable that in such a setting, forest management policies and practices in all parts of the world are coming under intense scrutiny.

When other kinds of natural resources are considered, such as minerals, rangeland, water, and so on, the associated problems faced by natural resource policy makers, decision makers and managers grow proportionately more diverse. Depletion rates, pollution, rehabilitation, and other issues not common in forest management come to the forefront.

In sum, the problems faced by natural resource managers at the present time are complex and difficult and becoming more so with each passing year.

Perhaps this is because we are recognizing that natural resources are finite and we are moved to do something more to preserve them; perhaps it is because we have better information about natural resources and a clearer scientific understanding of the processes which create and sustain them; perhaps it is the times we live in. Whatever the reason, the trend is clear: faced with increasingly difficult situations, policy makers, decision makers and managers are looking for tools to assist them, and they are turning to GIS technology with that in mind.

Role of GIS in Natural Resource Management

GIS technology has been associated with the mapping and management of natural resources, including forests, from the inception of its use some twenty-five years ago. Canada was one of the first countries in the world to make use of a large GIS for natural resource management as well as other purposes.

The uses to which GIS technology has been put in managing natural resources are well illustrated by some of the uses it has in forest management and forestry.

GIS continues to be used for simply automating the making of forest maps (automated cartography). At the present time, it can be truly said that GIS techniques produce maps which are equal to or superior to those produced by manual means. The evidence for this is the number of governmental and commercial cartographic organizations which are going over to GIS approaches to map production.

In importance just behind the production of conventional kinds of maps is the production of various kinds of thematic maps in an attempt to clarify users' understanding of the natural resources situation with which they must deal. The production of GIS-derived reports and statistics is probably equally important, especially for monitoring and management related purposes.

Many organizations make use of the modeling capabilities of their GIS software to analyze natural resources issues. Beginning with simple models and simulations, these organizations, over time and with the support of basic scientific research and better theoretical understanding, are creating more sophisticated and more reliable models. Some models simply automate the calculation of timber yields, help locate such land uses as haul roads or recreational facilities, help select timber for harvest or conservation, identify sensitive habitat for preservation, or are used to analyze possible alternatives approaches to managing a timber stand or forest. As confidence is gained in these applications, more complex and powerful applications of GIS modeling are likely to follow. Some of these more copmplicated modeling efforts are already underway; these attempt to predict where forest fires are likely to start and how they are best suppressed, what the effect of acid precipitation and other environmental insults will be on forests, and how rapidly certain wooded areas will become desert. Aspatial, process models are being combined with GISs to address the critical questions of how economic, meteorologic, hydrologic and other processes interact with geographically disposed natural resources.

Because GIS technology, when combined with Database Management System (DBMS) technology and with various data gathering techniques, makes it much easier to create and maintain comprehensive information about natural resources, many issues, which were not approached systematically in the past because the data were too costly to gather or the analysis too time consuming, are now being addressed explicitly. Instead of having to identify, fund, and staff a special study for each new problem, the existence of GIS makes it much easier to deal with special problems by means of query and reporting efforts not too much different from other kinds of routine management operations.

The combining of GIS technology with expert systems (based on principles of artificial intelligence), the use of Global Positioning System (GPS) technology to enhance data capture for GIS systems, and the use of image processing to provide more rapid updating of GIS databases are all examples of the interaction between GIS technology and other modern technologies with which it is often associated.

What remains to be seen, in this area of GIS application as in all others, is the extent to which GIS technology can do more than just help organize and rationalize policy making, decision making and management, important as that would be if it were accomplished. What remains to be seen, and what is potentially most important about GIS technology, is whether GIS technology can make an important contribution to the solution of the problems which have been sketched out above; in short, whether GIS technology can make a difference in natural resource management, whether that difference is measured by profits, healthier forests, conservation, habitat rehabilitation, or in some other way.

What Determines and Who Decides Where GIS Technology is Going?

A critical question in every applied technology field is "Where is the technology going?" The answer to it should determine the directions in which research and development are to go, it should determine marketing strategies for the future, and it should determine investment policies. A reliable answer to that can be of enormous value. But there are so many uncertainties and so many factors to take into account that any answer to such a question is an educated guess at best, and unforseen events, from the introduction of a new product to the outbreak of a war, can overturn even the most carefully calculated estimates.

GIS technology is driven as much, or probably more, by user wants as it is by developments in the fundamental underlying technologies. At ESRI, for example, we listen very closely to our users and customers as we lay our development plans each year. So while it seems entirely reasonable to ask a supplier of technology to guess what the users of the technology are going to want at some time in the future, it is a question which many suppliers would much rather be asking of their customers.

Beyond user needs and user wants, one also must consider what the capabilities and limits of the supporting technologies are or seem to be, what research promises for the future, what new and emerging technologies may offer, what resources can be brought to bear, how fast the field is growing, and a myriad other factors.

Two kinds of answers to the question will be given here: a fairly straightforward projection for the middle term, the next 5-10 years, and a vision of the period just after the turn of the century.

Where the Technology May Lead in the Next Decade

While improvements in technology may seem the most important elements of change in GIS technology within the next decade, this is not likely to be so. What is most likely to be important within the next decade is the rapid spread of GIS technology to new users.

At the present time, there are probably fewer than 100 000 users of GIS technology in the entire world; at the end of the decade, there are likely to be a million users. For every organization that has the technology now, ten may have it in the year 2000. The impact of GIS technology will be felt as these organizations move from manual analysis of geographic data to automated analysis. Moreover, these organizations will do so with an enormously richer base of experience than was the case for the earlier users of GIS technology. Really effective GIS technology, incorporating DBMS technology, only became widely available in the mid-1980's, and until the late 1980's, only a handful of organizations used the technology. But in the 1990's there will exist a very large experience base from the thousands of organizations which have been using GIS technology, often for a decade or more.

Data capture techniques will continue to improve slowly and this improvement, coupled with pressures for including more kinds of data and for wider geographic coverage, will fuel the increases in available GIS data resources. All these new users will thus have a much richer store of data available to them as they begin GIS use.

Within the next decade information about natural resources will be increasingly integrated and access to it will continue to move down through every natural resource organization. Organizations which deal with international forest management issues will begin to get access to global databases which contain the kinds of information they need. Commonly used databases will be up to two orders of magnitude larger than they are today and will be readily accessible through networks of varying spatial extent. This will mean that organization-wide, forest-wide, state-wide and nation-wide and applications even larger in scope will be easy enough to do that many will want to make their plans on these scales.

Models will grow in usefulness and become more widely accepted as decision support tools. The number of software organizations providing such models as a product, or performing GIS modeling and analysis for clients, will increase. These models will increasingly incorporate process and temporality as well as spatial data and their attributes.

Finally, practical and useful applications of expert systems, acting with GIS databases, will begin to come into use in natural resource management; at first, these will provide very specialized functions, quite possibly in forestry, but over time, as the expert systems prove their usefulness, their use will inevitably increase and change the way in which some management tasks are approached.

Where the Technology May Lead Us Just After the Turn of the Century

The question of where GIS technology 'is leading us' is not quite the same as 'where is the technology going to go', and the author will take advantage of that difference in this last section.

This section is considerably more speculative than the previous parts of this paper. It may be that neither the author nor those who read this section will live to see the natural resource management environment which it envisions. But one failure of those who predict the future is that they are often too conservative. This section tries to avoid that fault.

Sometime after the turn of the century, manual digitizing will, at last, give way to completely automated means of data capture, and organizations will begin to augment their current digital data with baseline data from much older hardcopy maps. This and other related developments will force much greater emphasis on efforts to standardize and integrate various types of data. Organizations specializing in this area, perhaps working on contracts jointly funded by many organizations, both public and private, are likely to arise as a result. New kinds of GIS workstations will need to be devised to support their efforts.

Remote sensing technology will continue incremental improvements and be coupled with data gathered by the first of a wave of ultraminiature sensing devices which will, later in the century, give rise to the 'instrumented universe': a universe where sensors, based on silicon chips or some related technology, will be broadcast through the natural areas of the world and will telemeter their data, via satellites, to various collection centers around the world.

Global GIS-based models with limited predictive capabilities will be used to provide routine kinds of predictions for limited geographic areas, such as more precise predictions of flooding following local precipitation. Global meteorological and atmospheric models will be more closely integrated with GIS than they are today, though fundamental improvements in our theoretical understanding of this interaction are likely to be further off in time.

Continuing changes in both the kinds of education and training required for natural resource management and the nature of the work will be occurring, with even less of managers' time spent in primary data gathering and field work and proportionately more time spent in working with information in various digested forms, especially new and richer GIS graphic forms.

Decision makers and policy makers will begin to have a third generation GIS-based decision support environment available to them. A generation of senior managers which has always known computers will be accustomed to their omnipresence; the simpler, more graphic, more transparent, and considerably more reliable support programs will be much more widely accepted and used. While the paperless office will not have arrived, displays of spatially referenced data will be so easy to create and so fast to produce that the use of ephemeral electronic displays will be routine aids to thinking about every kind of natural resource management problem. True three-dimensional map displays, with 'overflight' and zoom capabilities, with draped information, time sequenced displays, richer displays of thematic data over imagery, and similar kinds of capabilities will be widely available. These will be so effective that managers will have to be continuously conscious of the fact that the displays are not the reality, lest they be misled by their information resources.

Because the ability to transmit enormous amounts of data over long distances will have so markedly improved, much greater integration of international production, marketing, and trade information will be the norm. Correspondingly, more people and more governmental and private organizations will have some real insight into more aspects of the activities of all kinds of both government and private resource management organizations. This will likely sharpen some kinds of conflicts, although greatly increased sharing of data resources may head off other kinds of disagreements and instead favor more rational discussion and debate.

Expert systems and artificial intelligence will be more widely applied, with probably a few really critical successes already indicating that much more radical changes in natural resource management are to come as the century goes on.

On the international scene, in the absence of major wars or unforeseeable political developments, and if funding is wisely provided, there will be much greater sharing of natural resource data throughout the world. In particular, the countries of the former eastern bloc will be working with technological help from the rest of the world to plan the cleanup of the environmental problems which have accumulated there over the last hundred years or so. Their efforts, supported by the technologically advanced countries, will be a model which many less developed countries will find attractive and will attempt to follow. Fortunately, the cost to acquire GIS technology will have continued to fall so rapidly that virtually every natural resource agency which would find GIS useful will be able to afford it.

In the many cases around the world where habitat rehabilitation is needed, and where projects are just beginning, GISs will play an especially important role in informing people of what former habitats were like. They will also be used to estimate the possible success of such projects, to plan them, and then to monitor their success.

Throughout the world, some 50 years after the birth of GIS technology, the technology will be so widely accepted and so commonly used in natural resource management that it will have become, to a considerable extent, not just transparent to its users but, to a considerable extent, invisible to them. And meetings of the kind we are having today will be mostly memories of the past.

Conclusions

This is an exciting time to be working in the GIS field. We are in the rare position of being able to look simultaneously back to the beginning of GIS technology and to look forward to the time when it will be quite mature and used by tens of millions of people throughout the world.

While no one can predict the future, fairly reasonable extrapolations suggest that the use of GIS technology in natural resource management will expand rapidly in the years just ahead and that within two decades, the use of the technology will be a fundamental part of the daily and even hourly work of most natural resource managers throughout the world.

More to the point, there is evidence that GIS use will be helping to **solve** the real problems such managers face today and are going to face in the future.

Thank you all for allowing those of us who are developing that technology to be a growing part of your own increasingly critical work.

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Old Growth Forests: Can the Conflicts Be Resolved?

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Abstract

The forest resource is under pressure for uses other than timber. We must determine what the present situation is and whether multiple forest use demands mutually are exclusive.

In B.C., the Ministry of Forests controls 86% of the land base of the province. The primary controlling philosophy of the Forest Service is liquidation of all commercial old growth forest and its conversion into tree plantations. A tree farm is not a forest.

"For British Columbia, the meaning of integrated resource management depends on many factors, not the least of which is what the dec ision maker believes is 'allowable'...Many senior managers feel that other forest values, no matter what they might be (wildlife, water, fish, etc.) can only be protected so long as the prime mandate of the maximum rate conversion of natural forests to 'fibre' tree farms is maintained.

An allowable decision, therefore, is one which is possible without interference with the prime directive of maximum natural forest liquidation. Common Forest Service phrases such as 'all values considered,' and 'Integrated management' (multiple use), have little meaning outside this context."

If we look at the conclusions of the expert panel on forest management in Alberta, they are revealing about the structure of forest land administration and are valid observations for B.C. as well.

"The panel tells us that integrated management of natural resources on forest land in Alberta is good, at least conceptually, but deficient in application. Professionals responsible for non-timber values do not have the staff, funds or status within government to ensure balanced use of forest land. As well, the expert panel notes that input into forest planning occurs, even for the fish and wildlife department, only after the Alberta Forest Service has done the planning and developed the ground rules."

Introduction

Present Logging Practises and Multiple Use

About 90% of all forests logged in B.C. are clearcut and about 90% are old growth. Present clearcutting and road building methods have a destructive ecological impact with significant loss of biological diversity, loss of soil, critical wildlife and fish habitat, etc.

"There are several cogent scientific objections to the clearcut and slash burn methods still used by logging companies...The first is that destroying the vegetation damages the soil far more severely than had, until recently, been supposed. It has long been known that clearcutting kills off many of the fungi that attach themselves to tree roots and enhance the roots' ability to absorb water and nutrients from the soil...It has now been discovered from recent research done in the U.S. Northwest that the soil's water holding capacity, too, depends on the health of the living things within it...Remove all the trees and, worse still, clear and burn the remaining vegetation, and you kill the roots and starve the underground organisms on which good soil texture depends."

Present industrial forest use is not compatible with protection of biodiversity, soil, critical fish and wildlife habitat, community watersheds, wilderness, cultural and spiritual values, tourism and recreation that is dependent on a pristine landscape and the image of B.C. as supernatural. Other problems such as logging road construction increases human access into previously remote areas and has an impact on vulnerable wildlife populations.

Multiple use in B.C. has come to mean that timber use is dominant and is, in fact, single acceptable industrial use, to the exclusion of all other uses.

Determining the Extent of Old Growth in B.C.

The extent of old growth is not known in B.C. Its determination has never been a Forest Service priority. On the coast (coastal western hemlock and coastal Douglas fir zones), it is estimated that those two zones cover 6.5 million hectares. When this is netted down to commercial coastal forest, it is 4 million hectares, of which less than 1.7 million hectares is forested in trees over 250 years in age, the old growth). In another 17 years or so, all the coastal timber that is currently considered economic to log will have been liquidated. The shake out when the industry moves from logging old growth to logging second growth could be severe in certain areas but the present timber data are inadequate to predict these impacts accurately. Furthermore environmental constraints and other forest uses have not been adequately considered.

In a study soon to be released, titled "Inventory of Watersheds in the Coastal Temperate Forests of British Columbia" by Keith Moore, the following conclusions were reached:

Of the 90 primary watersheds larger than 5 000 hectares on Vancouver Island, only 5 are totally pristine. There is only 1 totally intact watershed larger than 20 000 hectares left on the entire south coast of B.C.

A 1988 study concluded that only 185 600 hectares of old growth are currently protected in parks and ecological reserves on the B.C. Coast. Around 50 000 hectares of old growth are logged annually on the B.C. coast.

Identifying Knowledge Gaps and the Data Required to Fill Them

It is quite clear that there are significant gaps in our knowledge about all the resources of the B.C. forest. Old growth has not been considered an issue of importance by the B.C. Ministry of Forests. There has been very little, if any, research into the structure, function and biological diversity of our original forests. Senior managers have, over the last three decades, set the highest possible rates of logging in all commercial forest areas to maximize timber production.

There has been increased interest in updating the timber inventory which is admittedly inadequate. However, the Forest Service has neither the staff nor the resources to do this job in an acceptable period of time. Furthermore, critical resources like soil and slope stability are not adequately considered. There is currently no legislation to ensure protect soil.

Very little effort has been directed into collecting data on other forest resources. Environmental managers lack the resources, staff and status within government to ensure balanced forest use. And there is no political will to change this. Wildlife managers have tended to concentrate their limited resources on high profile species like deer, elk, caribou and grizzly. Very little work has been done on biological diversity and especially on the multitude of organisms in the soil. Ministry of Tourism has finally realized that their resource is based on the land, previously they were just a marketing agency. They are just starting to gather information about their old growth forest landscape requirements.

Management of Old Growth

Representative areas of old growth, of sufficient size to be a complete ecosystem, such as intact watersheds, should be identified and protected in each ecoregion of the province. Significant areas of old growth, from the point of view of biological diversity, critical fish and wildlife habitat, environmental sensitivity, uniqueness, landscape landmark, cultural and spiritual heritage values, recreation and tourism, community watersheds, etc., should be identified and protected.

Current rates of cut presume the total liquidation of the commercially designated forest. True integrated resource management implies equal consideration of all resources of the forest. No logging must be an option. Therefore the AAC must be reduced to take into consideration all forest values. Environmental information must be collected and must be considered from the beginning of the planning process.

Delete from AAC calculations controversial areas and environmentally sensitive areas, and collect the data to identify them. Meares Island is an example.

Present logging practises must change to protect old growth characteristics and values. In Washington State, the Department of Natural Resources has just released a draft management plan called the **Olympic Experimental State Forest Draft Plan**. This could provide a model for better forest management.

It is no longer acceptable for our forest managers to maintain the status quo. There are legitimate alternatives that are beginning to take all forest values into account. Unfortunately, our forest managers are ill-equipped to apply a diversity of silviculture systems and there is a great deal of resistance to change.

Land use planning must be initiated that takes all forest values into account. Protection of community stability, diversification of local economies, the encouragement of value-added products and a fair return on our timber are essential. Community based forest control and planning, coupled with changes to the tenure system are necessary.

Recommendations

1. Legislation to adequately protect the environment and other forest resources is needed. Once enacted, laws need to be enforced. British Columbia needs a Biological Diversity Act, a Wildlife Habitat Act, an Endangered Species Act, a Wilderness Act, and a Forest Practises Act. This legislation must be accompanied by a Freedom of Information Act.
2. Ministry of Environment must have coequal status with the Ministry of Forests in decisions over land use in B.C.
3. Changes to the tenure system are necessary with a move towards community-based and controlled forests.
4. Move towards an open log market.
5. Introduction of a zonation system, where different land uses than logging are allowed to domine. This would protect areas of productive old growth where logging is excluded.
6. Increase the knowledge of all forest resources so that informed responsible decisions can be made.
7. Move towards a common database in all government ministries and better communication and coordination of information within and between ministries.
8. Increase government staff to ensure that an adequate environmental assessment is made for all land use decisions.
9. Intensive silviculture on identified commercial forest land base after area is netted down from deletions to protect the environm ent and other forest resources and values that are not, at present, adequately considered or protected. The use of slashburning, herbicides and pesticides are not acceptable silviculture tools.
10. Reduction of present AAC because it does not sustain all values. The principles of sustainable development must be adhered to, which is a balance between the environment and the economy.
11. Recognition that a tree farm is not a forest.

Old Growth Forests are a non-renewable resource.

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Old Growth Forests: Can the Conflicts Be Resolved?

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Vancouver, B.C.

Abstract

The 'old growth' debate is a recent phenomena which has arisen in part from mankind's respect for old lifeforms, be they human or trees. The issue is being complicated by emotional rhetoric designed to promote the interests of various parties. The issue can be defined simplistically in terms of "How much of B.C.'s land base supporting old growth forests should be preserved?".

A solution to the conflict requires an understanding of the four elements of old growth forest lands: biological/ecological, tourism/recreation, spiritual/heritage, and commodities. It also requires an understanding of the interests of the various parties to the issue. This understanding would suggest that the essence of the debate is not necessarily in the areas of recreation or special vanues/biological, but is essentially between those who wish to preserve large areas as wilderness and those who support the commodity use of most forest lands.

Understanding the nature of the debate and the interests of the parties in the debate leads to the conclusion that society can no longer support ad hoc decision-making with respect to land use. The parties to the debate should terminate their rhetoric and seek the information needed to support intellignet land use decision-making.

Introduction

The old growth debate is emotional, mystical, and arises in part from mankind's respect for old life forms, be they human or trees. It presents a problem in which it is very difficult to clearly identify the issues which lead to debate.

We hear or read statements such as 'all of B.C.'s old growth will be gone, extinct within 20 or 30 years'; 'that harvesting destroys old growth ecosystems'; 'that once gone, such ecosystems can never be replaced'; 'that harvesting old growth is essential to maintain the forest industry and B.C.'s standard living and its economy'; 'that maintenance of old growth forests are essential to the maintenance of life on earth (lungs of the planet)'; 'that maintenance of old growth is a prerequisite to maintaining our ability to draw tourists to Supernatural B.C.'; and 'that harvesting of old growth is essential for sustaining the economies and lifestyle of rural communities'.

In simplistic terms, the debate can be refined down to the question of "How much of B.C.'s land base supporting old growth forests should be preserved?". The key, I believe, is to determine how we in B.C. are to implement the recommendations of the UN World Commission on Environment and Development, better known as the Bruntland Report: **Our Common Future**, that nations should manage natural resources under the principles of sustainable development. How do we use natural resources in a way which sustains natural productivity while meeting the needs of mankind today and in the future?

Our first task is to correctly understand the issue, because this is the critical step in resolving any conflict. Old growth forest lands contain natural resources consisting of several elements: biological/ecological, tourism/recreation, spiritual/heritage, and commodities. The balancing of these elements on each unit of land is the issue.

The second step is to understand the interests of the various parties to the issue. Four interests can be readily identified:

1. Wilderness Preservation;
2. Special Value/Biological;
3. Commodities (wood, water, minerals, hunting, trapping, grazing); and
4. Recreational.

Of the four, special value/biological interests are generally agreed by all parties to be of primary interest. Therefore, I believe there is consensus that as a first priority, we in B.C. should seek early completion of the B.C. Ecological Reserves Program and that this task can be carried out without conflict. However, support and financial resources are needed.

Another of the four interests also raises relatively little conflict among the parties, and that is recreational. In the last month, the B.C. Government has issued it Parks Plan 90 as a blueprint for establishing Park areas representing all of the 59 defined B.C. landscapes. The Plan represents a well thought out process for identifying candidate areas, for involving communities and stakeholders in discussions leading to the understanding of the uniqueness of candidate areas, the values contained within the areas, identification of the impacts of the proposals on stakeholders and on the public interest, and for the purpose of refining specific proposals as to practical boundaries.

If the Parks Plan 90 process is adhered to, we should see new Parks being established in areas which study has shown to possess unique values and which fit into the needs of an overall provincial master plan. Having been developed on the basis of recognizing stakeholder and community interests, of planning to meet projected future recreational needs, and of compensating impacted stakeholder interests by a process which is sober, fair, and factually based, Parks Plan 90 is a mechanism for resolving conflict concerning how much old growth and other ecosystems should be set aside in parks. It is a comprehensive process which would replace the ad hoc resource use decision-making of the past with respect to park land designation.

The Parks Plan 90 process deserves everyone's support and constructive participation.

Now we are left with two other interests, commodities and wilderness preservation. Where is each coming from?

Commodities involves the use of the range of natural resources of any given area to meet the needs of mankind for fuel, food, water, and shelter. In comparison, wilderness preservation tolerates no extraction of products and no use which alters the so-called natural condition of the area.

Obviously, these interests are diametrically opposed. Commodities interests support the concept of wise use: a range of uses under integrated management. This includes designation of special management areas and special value protected areas as determined by evaluation of the available facts produced through studies carried out by resour management professionals. However, it requires the commitment of more professionals and more resources than currently is the case if the process is to work in the overall public interest and so that we have the informational lead-time necessary to make the better resource development decisions needed to prevent conflict.

Wilderness preservation interests, by definition, target large undeveloped areas and seek to place them off limits to any consumptive or non-consumptive use or management which would constitute mankind's interference with the process of natural development.

This polarity defines what we see in the press as the old growth conflict: the disagreement between those who feel that significant areas which are not yet developed should be never developed and those who see integrated management as the means for meeting the needs of people today and that of the much larger population tomorrow. The tactics in this conflict range from threats of job losses and community disruption, from selective reporting of results of management practices, to justification for preservation on the basis of attaining a predetermined 12% set aside. Although there are other tactics, I feel that these three represent the primary thrusts being used in the old growth debate.

Taking them one at a time, let's first examine the jobs issue. You are probably aware of the Valhalla proposal for the establishment of wilderness areas throughout the province. This Valhalla proposal has been made without the benefit of such studies as are involved in the Parks Plan 90 process and have not involved stakeholders in the development of the proposals. The proposal is justified on the basis that it would only impact the provincial annual allowable cut by about 3 1/2 %. The flaw in this simplistic approach is that the impact on local communities would likely be far in excess of 3 1/2 %.

By way of analogy, consider yourself as a proprietor of a pie shop. You have been given one pie to establish your business and it has been divided into 8 slices and is to be sold one piece per day for 8 days. After 6 days of aggressive marketing, you have sold 1 piece per day. In order to sustain your business and your employees, you are preparing another pie, but it will not be ready until day 9. In the meantime, you have 2 pieces of pie left, 1 each for the day 7 and day 8.

However, someone comes along and takes away one of these pieces without paying for it. Your business is left with a sales shortfall for day 8, one day before the new pie is ready. Can you pay your bills, pay your employees, keep the bank from foreclosing, and pay the running costs of your bake shop without the revenue from day 8? Yes, you can split the remaining piece in half and sell one-half on each of days 7 and 8, but your revenues are also halved and you will not likely be able to keep your operation intact.

In addition, you have been told that the ingredients needed to produce future pies will not be as available, in fact, these will only be 7/8th of your first pie, yet your existing shop and number of employees have been scaled to the original full-sized pie. It is obvious that you will have to begin immediately downsizing your operation, not only by first splitting the remaining piece of pie in two and selling half-sized pieces over days 7 and 8, but by preparing to sell 1/8 smaller pieces in the future.

This is the nature of the problem which concerns industry so much. The impact of old growth preservation is not only immediate through reduction in current harvest levels in proportion to the need to scale down operations to a lower level for the future, but also as to the netting out of the volumes in old growth set asides in order to immediately begin to spin out the residual remaining old growth until the oldest second growth reaches harvestable size. How can industry pay its taxes and its bills to the public and its creditors, and maintain employment when its revenues are cut and it has idle plants and employees,without compensation to companies, to employees, and to communities?

The second tactic involves the selective reporting of the results of past management practices. You have undoubtedly seen preservationist organization brochures and videos showing slides on mountain slopes, fresh slashburns on recently logged areas and dark pictures taken within young second growth stands placed opposite beautiful pictures of old growth forests. The intent is to suggest that every time we log, frequent slides occur which occupy vast areas, that slashburning destroys soil productivity, and that second growth forest are monocultural biological deserts.

However, I suggest that the facts are as follows:

- That all the slides which have occurred on logged areas over the past hundred years, and I agree that with today's knowledge that most of them could have been prevented, do not add up to even close to 1% of the total area harvested to date;
- Severe slashburning has damaged the growth potential of some sites, but again is preventable by today's knowledge and technology. In any case, it would not likely measure up to even 4% of the average growth potential of all areas harvested to date. In fact, many areas have benefited by removal of over-thick organic layers and through soil warming. On balance, there has likely been a net benefit from slashburning and certainly with today's knowledge and today's regulations, there must either be a benefit or nil impact on soil productivity before a slashburn is prescribed;
- You also hear that plantations are sterile biological deserts bereft of species and genetic diversity. In B.C., such charges simply cannot withstand scientific scrutiny. A recent attempt by one organization to portray plantations as vast areas of deformed off-site trees on the basis of selective extrapolation and interpretation of existing scientific studies was soundly debunked by the authors of those studies.

The third tactic I wish to address is the suggestion that 12% of Canada should be preserved in its untouched state as being something called for by the Bruntland Report. The facts are that the Bruntland Report noted that at present, nearly 4% of the earth's land area is managed especially to protect species and ecosystems, and that the scientific consensus was that the "total expanse of protected areas needs to be at least tripled if it is to constitute a representative sample of the earth's ecosystems."

Nowhere does the report say that Canada or any other single nation should protect 12% of its land area. The report does clearly suggest that representative portions of identified ecosystems should be protected where they occur. This means that some countries may happen to have only a few ecosystems on their land area while others may have more and the percentages should vary proportionally.

More importantly, nowhere in the report does it suggest protecting means preserving as wilderness. It calls for management of identified areas and areas adjacent to such areas in a manner which would sustain the ecosystem components as the basis of any land use decision. The implication is that use can be made of resources within the designated areas for various purposes provided that the prime objective of protection is maintained.

The Bruntland Report does not call for no use of 12% of Canada's land base by assigning wilderness preservation status. It does call for careful evaluation of the world's ecosystems and protection through management of these ecosystems so that representative samples can be sustained. It calls for the application of such management on areas which constitute three times that currently in existence, on the basis of where these ecosystems exist.

Within the context of wilderness preservation versus wise use for a wide range of commodity production, I believe that resolution lies in encouraging both paries to move away from the existing rhetoric to providing the public with facts. We should recognize that the tactics that have been employed to date have served only to obscure the need to carefully assess options after having first completed the appropriate studies by resource management professionals. We should accept that in recent times, land use allocations have been made on an ad hoc basis with respect to resource use and the results have not necessarily been in the public's best interest. We should accept that the issues are much more complex and that attempts to portray them as black and white options should be viewed with suspicion. And we should accept that community impacts must be fairly assessed, and that their concerns must be heard and considered in the decision making process.

Most importantly, we must practice sustainable development. Our priority must be to maintain balance in existing natural ecosystems as a basis for achieving an economically sustainable society. To do so, we need to better understand how natural ecosystems work, the impact of our activities on these systems, and the options we have for managing forest resources.

The information gap is wide. We all need to work together, on the same side of the table, so that we can increase our mutual understanding of how natural forest ecosystems function, and how they can be better managed to sustainably provide the full range of forest resources.

In summary, the challenge to all stakeholders in the wilderness/commodity old growth conflict is to jointly seek completion of the B.C. Ecological Reserves Program, to support and participate in the Parks Plan 90 process, and to commit to joint efforts to secure the full range of facts concerning proposals for old growth use or wilderness preservation as a basis for intelligent decision making.

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Old Growth Forests in British Columbia

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Abstract

Much of the forest cover of British Columbia is still in an old growth condition, although old growth forests are considerably reduced from their original extent. Old growth is fundamentally an ecological concept, and British Columbia's old growth forests generally conform to conceptual and ecological definitions, but they do not necessarily satisfy existing mensurational and structural criteria, especially in interior zones and at higher elevations. Characterization of old growth should be done within the context of an ecological classification, and by using multiple criteria including age, size, disturbance, stand composition, structure and function and minimum area. Development of working definitions for the various old growth forest types is the first requirement for a comprehensive research and management strategy for old growth in British Columbia. Process-oriented, functional, ecological research is the second major requirement.

Introduction

Old growth is a hot topic these days, one of the hottest in the resource management arena. Although most of British Columbia is forested and much of the province's forest cover is still in an old growth or mature condition, old growth forests are considerably reduced from their original extent and they cannot be reproduced under currently prevailing forestry practices. Furthermore, old growth forests have many values: ecological, scientific, economic, social, and cultural (Juday, 1988; Rolston, 1989). The ecological values of old growth may be thought of as intrinsic, whereas the others are human values that we place on the forest. Old growth forests also contribute much to the province's ecosystem and landscape diversity, which in turn are major components of overall biological diversity (Norse et al., 1986; National Science Board, 1989). Although old growth is but a part of the larger issue of conservation of biological diversity, recently in British Columbia the spotlight of public and management concern has been mostly on old growth (Caulfield, 1990; Fraser, 1990). The discussion and debate have been rather narrow, usually derivative, largely of facts and opinions from the western United States, and focussed on southwestern British Columbia. In this paper, I discuss some of the ecological and human aspects of old growth in British Columbia, and indicate some of the important information gaps and research needs.

Definitions of Old Growth Forest

Why Is Old Growth Difficult to Define?

Part of the reason for the old growth controversy is the confusion over concepts and definitions. The participants in the debate are not necessarily talking about the same thing when they discuss 'old growth'.

People are confused about just what constitutes old growth forest because it has no single definition that is all inclusive, universally applicable, and generally accepted (Thomas et al., 1988; Hunter, 1989). The most suitable definitions are largely qualitative and conceptual, and therefore somewhat fuzzy. Contributing to the confusion is the evolving concept of the old growth forest. Among early white settlers, old growth was just mature forest that had not yet been cut or cleared (old growth as Nemesis). Distinctions among climax forest, silviculturally mature forest, and other types of older forests were made in this century as the science of ecology and the profession of forestry developed and matured (Juday, 1988). The concept of old growth has evolved more rapidly in recent decades. Already in the eastern United States, old growth does not necessarily mean a forest that originated in the presettlement era, and in England, a forest established before 1700 is called 'ancient' rather than old growth. Today, some segments of our modern society perceive old growth as an aesthetic, experiential phenomenon that evokes awe and psychological and spiritual well-being (old growth as Sanctuary).

A simple definition of old growth could be 'climax forest that has never been disturbed by humans' (Hunter, 1989). But climax forests are notoriously difficult to characterize, and the concept of climax is itself elusive and often dubious. Furthermore, human disturbance in the broad sense is manifest everywhere in the biosphere these days.

Definitions and Attributes of Old Growth

Before examining their applicability to British Columbia forests, it would be helpful to review some of the existing definitions and attributes of old growth forests. Much of this information comes from recent work on the ecological characteristics of coastal old growth forests in the U.S. Pacific Northwest (Sollins et al., 1980; Franklin et al., 1981; Meslow et al., 1981; Alaback, 1984; Franklin and Spies, 1984; Maser and Trappe, 1984; Sedell and Swanson, 1984; Juday, 1988; Maser et al., 1988; Spies and Franklin, 1988; Thomas et al., 1988; Carey, 1989).

Definitions of old growth. The definitions can be classed as mensurational, conceptual/ecological, and spiritual/aesthetic.

A. Mensurational
- A stand 150-200 years or older (Alaback, 1984).
- Any stand beyond culmination of mean annual increment (average volume growth beyond its peak); and
- Stands greater than 140 years old and at least 30 m tall (Roemer et al., 1988).

B. Conceptual/ecological
- A stage of forest development characterized by greater diversity of structure and function than in younger successional stages (Thomas et al., 1988);
- The last of four successional stages in forest development: (a) pole sapling (b) young (immature), (c) mature, (d) old growth (overmature, climax) (Thomas, 1979). Foresters generally understand mature as that stage at which the stand achieves culmination of mean annual increment;
- A natural, mature stand of trees, not significantly altered by man, which may contain trees of various sizes, species, and ages that are part of a dynamic ecosystem (Forest Land Use Liaison Committee, 1989);
- Forests that are relatively old and relatively undisturbed by humans (Hunter, 1989); and
- "Old-growth forests are ecosystems distinguished by old trees and related structural attributes. Old growth encompasses the later stages of stand development that typically differ from earlier stages in a variety of characteristics that may include tree size, accumulations of large dead woody material, number of canopy layers, species composition, and ecosystem function" (Old Growth Definitions Task Group, 1989).

C. Spiritual/aesthetic
- Forests that people identify as cathedral-like, or that give them the old growth 'experience' (Rolston, 1989);
- Forests that are impressive to most people because of the size of the trees, the quiet within the stands, the subdued and broken lighting, and the humbling scale; and
- 'Ancient' forests that are revered for their heritage value and scarcity (Rolston, 1989).

Attributes of old growth. Old growth is fundamentally an ecological concept, and British Columbia's old growth forests generally conform to conceptual/ecological definitions as above, but do not necessarily satisfy all mensurational and structural criteria. The age at which old growth develops and the specific structural attributes that characterize old growth vary widely according to forest type, climate, site conditions, and disturbance regime. Typically, old growth is distinguished from younger growth by several of the attributes listed in Table 1. These attributes include structural, compositional, functional, and aesthetic features.

All old growth forests do not possess all these attributes. Old growth can include both older forests dominated by persistent pioneers, such as fire-dependent lodgepole pine, and forests in later successional stages dominated by shade-tolerant species. Stands do not have to be climax to be old growth, nor is old growth necessarily 'virgin' or 'primeval'. Old growth can develop following human disturbances. Disturbance is an integral part of the internal dynamics of many old growth forests (Lertzman and Lee, 1990). Canopy openings resulting from death of overstory trees often gives rise to patches of small trees, shrubs, and herbs in the understory (gap dynamics of Stewart, 1986; Denslow and Spies, 1990). But rates of compositional and structural change are slow relative to younger forests. Different stages or classes of old growth occur in many forest types.

Table 1. Attributes of coastal old growth forests in northwestern North America.

Structural

- wide range of tree sizes and ages;
- large average tree spacing and diameter;
- deep multilayered canopy of mature and 'overmature' trees;
- individual large, old, live trees;
- large amounts of coarse woody debris in the form of snags and downed logs;
- horizontal patchiness in both the understory and overstory; and
- vertical diversity:different tree species and heights.

Compositional

- usually two or more tree species;
- understory saprophytic plants and arboreal lichens; and
- support highly specialized and adapted animal species, including cavity nesting birds, canopy dwelling animals such as bats and flying squirrels, other small mammals such as shrews and mice, and large mammals, typically deer, elk and grizzly bear.

Functional

- have existed as stable communities for the latter decades or centuries of their existence;
- high understory productivity of shrubs and herbs;
- detritus-based food webs;
- conservative nutrient cycles, highly nutrient-retentive with rapid internal cycling; important pathways for fixing nitrogen;
- produce high quality water and fish habitat;
- primary production high but so is respiration, so these forests tend to be stable in terms of woody biomass accumulation; and
- produce highly valued wood.

Spiritual/aesthetic

- heritage values;
- evoke respect for elders (veneration of the aged);
- strong lines; humbling scale; colonnade effect; and
- tranquillity; subdued lighting; patches of light and shade; zen views; structural complexity.

Applicability of Existing Definitions and Attributes to British Columbia Old Growth Forests

Old growth is fundamentally an ecological concept, therefore it would be wise to deal with the old growth issue in an ecological context, at least initially. Economic, social, aesthetic, and political considerations can be applied later to either cloud or clarify the ecological vision.

British Columbia has 14 biogeoclimatic (ecological) zones, and each of the 12 forested zones has many different ecosystem types (Pojar et al., 1987; Meidinger and MacKinnon, 1989). It is not surprising that old growth definitions and attributes developed from work in coastal Douglas fir (*Pseudotsuga menziesii*) forests apply only in a general sense to the many kinds of old growth forests in British Columbia. Table 2 presents a review of the available information to determine the extent to which existing definitions and previously described attributes of old growth are applicable to the forests of our province.

Old growth forests in British Columbia generally fit the conceptual definitions, in that they are relatively old, older than the average catastrophic disturbance interval; (Hunter, 1989), composed of trees that have exceeded the average life span for the species, more diverse than younger stands, and relatively undisturbed by humans. However, in some parts of the province, forests that are relatively undisturbed are rare because logging, underburning, and/or cattle grazing has been extensive.

If old growth was considered synonymous with the climax stage of succession, some old growth forests in the wetter ecological zones of British Columbia could be termed climax. However, many interior forests have regenerated after catastrophic events such as fires or insect outbreaks, and therefore individual stands have not often reached a self-perpetuating climax state.

The age and structural features of the province's old growth forests have been controlled, to a large extent, by natural disturbance regimes. Old growth in western Washington and Oregon has been characterized by stands 150 to 200 or more years old, stands that have a wide range of tree sizes and ages, a deep multilayered canopy of mature and 'overmature' trees, widely spaced large trees, and significant amounts of coarse woody debris in the form of snags and downed logs. In British Columbia, coastal Douglas fir old growth forests usually possess these attributes. In the dry southern interior zones, frequent ground fires have resulted in ponderosa pine (*Pinus ponderosa*) and Douglas fir forests of large, widely spaced trees often older than 200 years. But there is a limited amount of downed woody debris and the tree canopies sometimes are not deep and multilayered.

In areas where catastrophic fires have been frequent, including the Montane Spruce, Sub-Boreal Pine-Spruce, Sub-Boreal Spruce, and Boreal White and Black Spruce zones (Meidinger and Pojar, 1991), forests often do not survive for as long as 150 years. These stands can be mature and often have abundant downed woody material, but usually have smaller trees and less structural diversity than older stands.

Forests that have been disturbed less frequently by catastrophic fires, including many stands in the Interior Cedar - Hemlock and Engelmann Spruce - Subalpine Fir zones, are more similar to coastal old growth stands. These forests are structurally diverse, have large widely spaced trees and abundant downed woody material, and 300 years could be a more typical minimum age for old growth.

Detailed definitions, specifying the sizes and number of trees and snags and amount of downed woody debris, have been developed for some US old growth coastal forests

Table 2. Applicability of some old growth criteria to mature forests in different ecological zones of British Columbia.

Criteria	Forest zones[1]										
	PP	IDF	MS	SBPS	SBS	ICH	ESSF	BWBS	CDF	CWH	MH
Mensurational											
age 150-200 yrs or older[2]	y[3]	y	?	n	n	y	y	n	y	y	y
beyond culmination of MAI	y	y	y	y	y	y	y	y	y	y	y
≥140 yrs old and ≥30 m tall[4]	s	s	s	?	s	s	s	?	s	y	s
Structural											
wide range tree sizes & ages[5]	y	y	y	n	y	y	y	y	y	y	y
deep multilayered canopy[5]	n	y	y	n	s	y	y	s	y	y	s
large avg. tree diameter[2]	y	y	s	s	s	y	y	s	y	y	y
indiv. large old trees (25/ha ≥l m diam.)[5]	?	?	?	?	?	?	?	?	?	?	?
much var. in mean tree diam.[2]	y	y	y	n	y	y	y	y	y	y	y
37 stems/ha ≥ 50 cm diam.[5]	?	?	?	?	?	?	?	?	s	s	?
large avg. tree spacing[2]	y	y	s	n	s	y	y	s	y	y	y
2 or more tree species[5]	n	n	s	n	s	s	s	y	y	s	s
abundant coarse woody debris[6]	n	s	y	y	s	y	y	y	y	y	y
exhibit decadent features[6]	y	y	y	y	y	y	y	y	y	y	y
contain snags[5,6]	y	y	y	y	y	y	y	y	y	y	y
snags (≥25/ha)[6]	?	?	?	?	?	?	?	?	?	?	?
down woody mat. ≥37 tons/ha6	?	?	?	?	?	?	?	?	?	?	?
Functional											
high understory productivity[2,5]	?	?	?	n	s	s	?	?	s	s	s
Conceptual/Ecological											
relatively old[7]	y	y	y	y	y	y	y	y	y	y	y
relatively undisturbed by human activity[7]	n	n	y	y	y	y	y	y	s	y	y
climax or shifting steady state	y	y	y	y	y	y	y	y	y	y	y
older than avg. disturbance interval	y	y	y	y	y	y	y	y	y	y	y
avg. trees reached life expectancy for species	y	y	y	y	y	y	y	y	y	y	y
more diverse than younger stages[8]	y	y?	y	y	y	y	y	y	y	y	y
natural mature stand, not much altered by man, may contain various size, spp., and age trees9	y	y	y	y	y	y	y	y	y	y	y

[1] Forested ecological zones (Meidinger and Pojar, 1991): PP - Ponderosa Pine, DF - Interior Douglas Fir, MS - Montane Spruce, SBPS - Sub-Boreal Pine - Spruce, SBS - Sub-Boreal Spruce, ICH - Interior Cedar - Hemlock, ESSF -Engelmann Spruce - Subalpine Fir, BWBS - Boreal Black and White Spruce, CDF - Coastal Douglas Fir, CWH - Coastal Western Hemlock.

[2] Alaback (1984).

[3] y=yes, n=no, s=somewhat or sometimes, ?=unknown.

[4] Roemer et al., (1988).

[5] Spies and Franklin (1988).

[6] Habeck (1989).

[7] Hunter (1989).

[8] Thomas et al., (1988).

[9] Forest Land Use Liaison Committee (1989).

(Alaback, 1984; Spies and Franklin, 1988). It is unlikely that these definitions apply to most forests in British Columbia, although they are probably appropriate for coastal Douglas fir stands and some forests of the Coastal Western Hemlock zone.

Criteria

Here are some considerations relevant to the development of criteria for defining old growth.

Conceptual. Will second-growth plantations develop into old growth? This is theoretically possible, but such long-rotation management is currently anomalous in our intensively managed landscapes. There is no guarantee that such old growth renewal would also replicate the original biological diversity, or provide suitable habitat for old growth-dependent wildlife, or that such wildlife would still be around.

Disturbance. In the interior, fire, insect outbreaks, and windthrow are the most frequent, large-scale, natural disturbances. On the coast, the most frequent catastrophes are windthrow, mass movements, and insect outbreaks; fire is less frequent but in the long term is probable, at least in drier coastal regions. A coastal watershed on the order of 2000 ha or more could probably buffer indefinitely just about any natural catastrophe. A much larger area would be required in the interior.

Mensurational/structural. Available evidence suggests that the important structural and functional attributes develop with age, and in British Columbia this means in stands older than 150 to 200 years. Although age may not always be a reliable indicator of old growth status, it is one of the few criteria that could be used to identify the extent of old growth in the province, using existing forest cover data.

Some of the stands that satisfy the age criterion are not in the climax state, for example, the western hemlock (*Tsuga heterophylla*) and amabilis fir (*Abies amabilis*) stands that originated after windthrow on northern Vancouver Island, but in other respects meet the criteria for old growth.

Height and diameter criteria should be flexible, depending on what is understood by 'forest' (e.g., stunted subalpine stands). Structural criteria will have to be developed later using available information from the Ministry of Forests' ecosystem program and new data as they are gathered.

Functional. The development of functional criteria will require considerable research into old growth forest ecosystem processes and functioning. Work in the United States suggests that we should begin with baseline studies to determine the ecological roles of large woody debris and to characterize nutrient cycling, microclimate, water balance, and primary production of different old growth ecosystems.

Minimum Area. Minimum area and the effects and implications of habitat fragmentation have yet to be determined; in some subzones and for some forest types, the issue is already foreshadowed by what is left, and patterns of land tenure and use. Even if patches of forest are left, they could be too small or too isolated from other patches to function effectively as habitat for old growth-dependent wildlife (Harris, 1984; Norse et al., 1986).

Proposed Approach

We propose that a general conceptual or ecological definition of old growth forests be adopted, and then working definitions for all ecological zones and major forest types (after Eyre, 1980) be developed. Hunter (1989) argues that we should first consider a set of age and disturbance criteria that are likely to have ecological significance. For example, has the forest reached climax, or at least a 'shifting mosaic, steady state'? Is the forest older than the average interval between severe disturbances such as wildfire and windthrow? Have the dominant trees reached the average life expectancy for that species? Is it a virgin forest?

Once appropriate age and disturbance criteria are chosen, forest ecologists could develop a unique old growth definition for the major forest types of the province's ecological zones. I recommend that an old growth scorecard (Raphael et al., 1989) or index of 'old growthness' (Spies and Franklin, 1988) be developed for each forested biogeoclimatic subzone (Pojar et al., 1987) and each major forest type in British Columbia. These specific ecological definitions should include forest structure and associated plant and animal species.

Another issue that must be addressed is the minimum area required to maintain wildlife and fish habitat and biological diversity. Minimum size for a viable old growth stand is difficult to specify because it depends on management objectives and on the nature of surrounding areas. However, it will still be necessary to specify for a given old growth stand a minimum size below which 'the extent of edge influence (alteration of interior stand conditions) and vulnerability to catastrophe are unacceptable based on management objectives' (Old Growth Definitions Task Group, 1986).

Conclusions

What I have attempted to do in this paper is to present a balanced portrait of old growth forests in British Columbia and some recommendations as to how they should be characterized. Definitions of old growth should be developed within the context of an ecological classification, by ecological zone and subzone, by forest type or ecosystem, and should use multiple criteria including age, structure and function, composition, disturbance regime, and minimum area requirements. In addition to working definitions of British Columbia old growth forests, we also need research into the basic, but poorly understood, processes and functions of these internationally significant ecosystems.

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Draft Obituary for a User Drowned in Data

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Abstract

Over the last 10 years, GIS has shown all the symptoms of an immature industry; rapid developments, an emphasis on tools rather than applications, and its existince as an island of technology rather than as a part of the landmass.

A more valid way of approaching GIS is from the point of view of the data and the user. A variety of organizations have made strategic investments in hardware, operating systems, and spatial and aspatial databases. In addition, billions of dollars of data investment lie in map drawers, slides, photos, and lately, in GPS and satellite data. This data is increasing by terrabytes per day, faster than our ability to find it and to process it. Users are ancient unsung information mariners lost and drowned in data.

GIS, like a telescope, is a tool which changes our view of the world. How will users handle the tool? How will we train the users? While the direction of the technology is important, other issues are vital. Applications and interfaces, management and protection of existing databases and data investments are all key issues. Method developments for minimizing data and systems integration costs are an emerging necessity. As an industry, we must deliver results to professionals and remove ourselves from the current reliance on GIS technologists. Information management, not information technology, is the vital issue.

The requirements imposed by the United States Federal Government are beginning to be a major factor in GIS strategic thinking and product development. The OSI model and the future DTS standard are steering GIS product direction towards a unified environment for data, application development and systems architecture. Full data management is essential and should include determining redundancy, a ssuring security, testing integrity, journalling, imaging, accepting and processing spatial and aspatial data, using intuitive user interfaces with scalable architecture independent of hardware, RDBMS and GIS. This paper examines user needs, data strategies and requirements to arrive at an application environment that is dynamic, that uses off the shelf products and that integrates all major current GIS technologies in a way that minimizes systems integration costs. Such a dynamic and integrated GIS approach is feasible and deliverable by the end of 1992.

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Client-server Computing: Computing for the 90s

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Abstract

The trend towards client-computing is well entrenched for the 90s. But the concept of the client-server model is not new. The world was introduced to client-server computing in the early 1960s with Digital's introduction of the first computer with direct user access. The concept was expanded with Digital's introduction of the distributed timesharing style of computing. The basic concept is the same: connect users to the resource they need to get their jobs done. The difference lies in the location of the resources and the communication between users. Client-server computing began to gain in importance as the user community grew more computer literate. Movements in design automation, factory automation, office automation and the use of more intelligent PCs and workstations have provided the most recent emphasis.

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Technology and Sustainable Forestry: How Can GIS Help Solve Forest Sector Problems?

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Abstract

With rapid advances in computer technology, our capacity to manipulate, integrate and display data far exceeds our ability to collect the relevant source information and to develop applied models for integrated management. Current research investments in developing GIS and knowledge-based models and utilizing databases efficiently for resource management are inadequate. Concerted cooperation is needed between political, industrial and academic sectors in order to maintain sustainability options in forestry in the next century. Is forestry research finding solutions fast enough? What are the consequences of low investment in research in this key area?

Concurrent Session 1

Forest Management - Industrial Experiences I

The CAMAS Project: Building a Computer-assisted Management and Analysis System for Natural Resource Managers

Digital Forest Management: Canfor's Experience

From Research to Production: Using GIS and Image Processing to Map Vegetation on 30 million Acres of National Forest Lands

GIS in Forestry Taxation in Finland

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The CAMAS Project: Building a Computer-Assisted Management and Analysis System for Natural Resource Managers

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Abstract

Integrated resource management and multiple use planning have emerged as imperatives for today's natural resource managers. While geographical information systems (GIS) organize large volumes of spatial and associated non-spatial attribute data, they do not furnish all of the tools necessary to make decisions whose final results may not be known for decades or centuries. Natural resource models that allow managers to simulate and analyze management and planning alternatives must be integrated with a GIS. The Computer-Assisted Management and Analysis System (CAMAS) supplies the conceptual framework for integrating GIS, database management system (DBMS), natural resource modeling, and master database maintenance software into one coherent package. The master databases serve as the central repository for all of the attribute information used by the GIS and the models. A prototype CAMAS was developed for the Lubrecht Experimental Forest by linking PAMAP GIS, FoxPro DBMS, the Stand Inventory System (SIS) which incorporates several forestry models, and an attribute management module, which provides input, editing and reporting facilities for the master databases. Our faculty, staff, students and forest manager are currently using this microcomputer-based system and reviewing it for ease of use, accuracy and decision support capabilities.

Introduction

In 1983 two critical needs were identified by the faculty and staff of The University of Montana School of Forestry. First, as increasing numbers of private, state and federal organizations adopted geographical information systems (GIS) for natural resource management, it was crucial to the School's educational mission to incorporate GIS technology into its curriculum. Second, to organize and maintain decades of vital data and to improve forest management and planning, the School of Forestry's Lubrecht Experimental Forest (Lubrecht) wished to acquire a GIS. In order to meet these needs, the School developed an informal plan to purchase a GIS and the associated hardware as soon as it became financially feasible.

A six-month formal planning and evaluation process culminated in 1986 with the creation of the Geographical Information Systems Laboratory at the Montana Forest and Conservation Experiment Station. The GIS Laboratory was established to provide facilities and support for teaching GIS courses, to incorporate GIS technology into the School's curriculum, to encourage the use of GIS in research projects, and to install a GIS as a management tool for Lubrecht and its data. With the mandate to purchase a GIS, we wanted to acquire a system that offered the maximum functionality and flexibility. While a GIS had significant utility as an organizational and graphical display tool, our interest lay in its powerful analysis, management and planning capabilities (Burrough, 1986).

Through our evaluation process we narrowed our GIS choices down to those that were fully functional on a microcomputer. We had two reasons for selecting a microcomputer to run our GIS. The first was the microcomputer's low cost to the students, staff, faculty, researchers and natural resource managers we envisioned using the system. The second was the pattern of microcomputer development itself. Technology was changing so rapidly that a microcomputer capable of supporting serious GIS use was becoming more and more powerful at a lower and lower cost.

While we would initially purchase only one vendor's GIS software, we were already planning to obtain a variety of other systems to improve support for teaching GIS courses and to encourage expanded use of GIS in research. Students could then be exposed to the strengths and weaknesses of different geographical information systems as we used them to illustrate spatial analysis concepts. Researchers would benefit by being able to choose the package which most closely met their analysis requirements and level of expertise.

Because the School had faculty, staff and students in range resources management, recreation resources management, recreation program services, resource conservation, and wildlife biology in addition to forest resources management, we wanted to introduce GIS technology into all of those areas. However, this technology would have to be made as easy to use as possible, since most of the School's potential GIS users were unlikely to become GIS experts just to use it. Besides receiving general GIS support for their courses and acquiring better interfaces to the natural resource modeling software used in the curriculum, the faculty and staff expressed an interest in integrating the modelling software with several GIS packages to enhance teaching and research efforts.

After considerable discussion within the School, it was decided that the Laboratory's research focus would be the utilization of GIS technology as one component of a well-integrated, flexible, easy to use decision support system for natural resource analysis, management and planning. We conceived a plan to develop such a tool, the Computer-Assisted Management and Analysis System (CAMAS), which would furnish the following:

1. A user-friendly environment that facilitated the teaching of spatial analysis concepts in GIS courses and workshops;
2. A standard interface for the natural resource modeling software used in the School's curriculum;
3. Spatial and non-spatial attribute analysis tools used for natural resource research by the School and its cooperating outside agencies; and
4. A decision support system for the improved management of Lubrecht and its data.

System Philosophy

As Covington (1988), Densham (1989), Reimer (1989), Honea (1990), and others have observed, a GIS by itself does not supply all of the decision support tools needed by natural resource managers. In fact, a GIS is but one component of a spatial decision support system (SDSS). Geoffrion (1983) identifies six characteristics which may be used both to define SDSS and to distinguish SDSS from GIS:

1. "They are used to tackle ill- or semi-structured problems - these occur when the problem, the decision-maker's objectives, or both, cannot be fully and coherently specified.
2. They are designed to be easy to use, the often very sophisticated computer technology is accessed through a user-friendly front end.
3. They are designed to enable the user to make full use of all the data and models that are available, so interfacing routines and data base management systems are important elements.
4. The user develops a solution procedure using the models as decision aids to generate a series of alternatives.
5. They are designed for flexibility of use and ease of adaptation to the evolving needs of the user.
6. They are developed interactively and recursively to provide a multiple-pass approach which contrasts with the more traditional serial approach - involving clearly defined phases through which the system progresses."

To effectively support decision-making for complex spatial problems, an SDSS integrates a variety of spatial and attribute data, facilitates the use of analytical and statistical modelling, conveys information to the natural resource manager through a graphical interface, and both adapts to the manager's style of problem-solving and is easily modified to include new capabilities (Keen, 1980).

With these points in mind, we set out to build the Computer-Assisted Management and Analysis System, an SDSS for natural resource analysis, management and planning, so that it would possess the following characteristics:

1. The standard easy to use interface, which could be utilized equally by novice computer users, occasional

CAMAS users and power users who employed CAMAS to solve complex spatial problems every day, would eventually be used to access all natural resource modeling and GIS software within the School. After the user had learned about each of the models and GIS packages, the by now familiar front end would permit him to coordinate the use of all aspects of CAMAS.

2. The natural resource modelling software would be transparently linked to the master databases through a database management system (DBMS), so users would be prompted for input only if it did not already exist in the databases. Over time, a model's interface would be changed to conform to the look and feel of the system's front end.
3. New temporary databases would be created to allow one model's results to become input for another model. New databases would also be built to contain the results of alternative solutions.
4. CAMAS would be modular, flexible, easy to maintain and composed of as much commercial software as possible. This would speed development and permit the incorporation of innovative programs as soon as they became available. New models could easily be added or subtracted to support the different requirements of range, recreation, conservation, wildlife and forest managers.
5. Beginning as a prototype running under DOS on a microcomputer, CAMAS would evolve iteratively, so its users would have a strong voice in its development. The modular design of CAMAS would be advantageous if user specifications dictated porting it to other computers and operating systems.

System Design

Four key modules have been identified in SDSS architecture by Armstrong (1986): a DBMS; analytical models; graphical display and report generators; and a user interface. Densham (1989) notes, "To the programmer, the modularity of the system facilitates software engineering; to the SDSS user, however, the system appears to be a seamless entity."

Due to the demands on Lubrecht's manager, the School of Forestry's Lubrecht Experimental Forest was chosen as the site of our pilot project. Before we could produce an SDSS to meet Lubrecht's analysis, management and planning needs, we had to build the master databases which would contain the decades of Lubrecht data in a form more useful not only to Lubrecht's manager but to researchers as well. From the beginning, we considered the existing attribute data as the heart of any system we would develop. With the addition of the spatial data, we would have the basis for creating an SDSS. Building the master attribute databases and digitizing the master spatial databases would take almost two years.

The core of CAMAS is its database managers. In our current implementation of CAMAS, these consist of FoxPro DBMS (FoxPro) for attribute data and PAMAP GIS (PAMAP) for spatial data. In our view, one of the functions of any GIS is that of spatial data management. While this may change in the future if database management software gains the tools and data structures necessary to efficiently handle spatial data, for now our GIS is the best spatial data manager available to us.

We have selected FoxPro because it is extremely fast, provides dBASE compatibility, has an impressive user interface and possesses a powerful software development environment. Because Lubrecht's attribute data will inevitably grow and because we have decided to develop CAMAS on DOS-based microcomputers, we felt that it was very important to purchase a DBMS which had exceptional performance. Since almost all of the School's existing data, including that of its cooperators, was in dBASE format, dBASE compatibility was a requirement. Using the FoxPro development environment, we could immediately start writing code for CAMAS.

PAMAP was chosen for several reasons. It has full functionality on a microcomputer, one of only two systems that did so at the time we evaluated GIS software. No special hardware beyond the addition of a math coprocessor is required to run PAMAP, and its menu-driven interface presents a gentle learning curve to our users. Originally developed with natural resource applications in mind and having very solid vendor support, it satisfied our initial requirements remarkably well.

Natural resource modelling and analysis software forms CAMAS's middle level. The Stand Inventory System (SIS) is the initial model incorporated into CAMAS, with other models to follow as soon as users require them. PAMAP furnishes its wide variety of continually improving spatial analysis tools to this level of CAMAS.

When a model is first integrated into CAMAS, it keeps its original interface and report generator. However, our interest is not in its front end or report facility, but in the portion of the model that manipulates the data. In fact, we will strip the model down so that it becomes a data transformation engine.

In the next phase of integration, the model is linked to the master databases so that the user has to enter only the data not found in them. The report generator is redesigned to create reports in the format preferred by Lubrecht's manager, to update the master databases when appropriate, and to build temporary databases which can be used as input to other models or to PAMAP. Connected to the model through the master and temporary databases, PAMAP can be used to display its results.

In the last stage of integration, the model's original interface is replaced with an easy to use front end which takes full advantage of the CAMAS environment. The report writer is modified further to give the user the flexibility to design custom reports, drawing on the master and temporary databases.

After merging SIS, which provides forest inventory and stand growth simulation modules, into CAMAS, we are now receiving user feedback before proceeding to the next phase of integration. Since SIS is the first natural resource model to be incorporated into CAMAS, it will go through the full development cycle, with user feedback at each stage, before any other models are completely integrated into CAMAS.

The top level of CAMAS is an event-driven pull-down menu interface currently written in FoxPro. The keyboard, a mouse or a digitizing tablet emulating a mouse is used to select among the following menu items:

1. System - This choice provides the user with the most commonly used DOS file and disk management functions, file backup and restore utilities using commercial software, and a general description of CAMAS.
2. GIS - This option allows the user to run either PAMAP or OSU MAP for the PC.
3. DBMS - This selection accesses FoxPro or the attribute management module, which gives the user the data input, verification, editing and reporting tools needed to maintain Lubrecht's master databases.
4. Models - This item currently runs SIS and its various components so that the user can perform assorted analyses on Lubrecht's data.
5. Exit - This pick lets the user exit CAMAS.

Because the user can move easily from SIS to the attribute management module to PAMAP to the DOS functions to FoxPro to the backup and restore utilities in any order, CAMAS provides the flexibility needed in an SDSS.

Uses of CAMAS

CAMAS is initially being used to support the School's GIS courses. It permits the students to manage their own files and to use PAMAP and OSU MAP for the PC to learn about geographical information systems and spatial analysis. We are receiving feedback from them on the interface's ease of use and the suitability of CAMAS's basic functions.

The GIS Laboratory's staff is using CAMAS in their daily work. We hope that CAMAS's interface and performance will encourage more research using GIS.

Lubrecht's manager and his assistant are employing CAMAS to improve their knowledge of PAMAP and spatial analysis, and to learn the capabilities of SIS. CAMAS, with the attribute management module and PAMAP, is simplifying the annual update of Lubrecht's master databases. Lubrecht's manager is also working closely with us to enhance CAMAS's decision support facilities.

This spring our senior level Project Design and Analysis class will use a new version of CAMAS, which links PAMAP and SIS, in a natural resource planning exercise. They will also provide feedback that will make CAMAS a more powerful decision making tool. As we add new models, more courses in the School will have the opportunity to use CAMAS.

Plans for Future Development

For the foreseeable future, we will be striving to improve CAMAS's interface. Since almost all of our users will spend only a fraction of their time using CAMAS, we need to make sure that they will not have to re-learn the system every time they want to use it. Because CAMAS will eventually be the front end to all of the natural resource models used in the School, our users will be able to focus on the operation of the models themselves, instead of worrying about the idiosyncracies of their original interfaces. With CAMAS, our users should be able to use the models and GIS together to make management and planning decisions about their study areas.

New models will continue to be added to support work in range resources management, recreation program services, recreation resources management, resource conservation, wildlife biology and forest resources management. Our integration priorities will be based on teaching, research and Lubrecht management needs. That way, we are always working on the models which will see immediate use and be of the most benefit to our users.

To meet the requirements of the School's GIS courses, other GIS packages, like Arc/Info and MapInfo, will be added to CAMAS. If our users demonstrate a need to have the natural resource models linked to a GIS besides PAMAP, we will also undertake that job.

Each development iteration will focus on improving the performance of individual modules as well as the whole system. The modularity of CAMAS will also be increased to make the system's maintenance simpler. As other environments, like Windows and OS/2, come into common use, we will consider porting CAMAS to those which offer our users a better interface, enhanced performance and expanded capabilities. With the continuing feedback of our users, we can only improve CAMAS as an SDSS.

Summary

Spatial decision support systems (SDSS) which incorporate geographical information systems (GIS) furnish today's natural resource managers with the tools necessary for analyzing, managing and planning natural resource use. The GIS Laboratory's Computer-Assisted Management and Analysis System (CAMAS) provides the conceptual framework for integrating GIS, database management system (DBMS), natural resource modelling, and master database maintenance software into an SDSS. A prototype of CAMAS which incorporates PAMAP GIS, FoxPro DBMS, the Stand Inventory System and the attribute management module is presently being used to support the School of Forestry's GIS courses, research using GIS and management of Lubrecht Experimental Forest. Our users are currently reviewing CAMAS for ease of use, accuracy and decision support capabilities.

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Digital Forest Management: Canfor's Experience

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Abstract

Canfor's Englewood Division acquired a GIS two years ago. Within this period, we have developed the framework necessary to digitally manage our 200 000 hectare Tree Farm License. This paper focuses mainly on the role GIS played in our Management and Working Plan. The plan is produced every five years to document and justify our forest land management techniques. It addresses issues of current and long-term wood supply; the 200 year horizon, silviculture regimes, and habitat requirements. GIS was used in conjunction with a forest estate model to test numerous management scenarios. Important issues included the decision to load 'dirty' data, the acquisition of contour data, networking data, raster/vector processing, restructuring for feature codes, and becoming a 'beta' test site for GIS software. In addition, we discuss our objectives for 1991 relating to training, wildlife habitat, ambrosia control, a cruise prediction system, coordinate geometry and other goals.

Introduction

The complexities of forest management are demanding more detailed information for better planning and decision making. The ability to evaluate the interaction of standing inventory, geographic and biological variables, fibre flow and economic considerations has become a necessity. Increasingly, forestry is becoming very data intensive, with a need to access management data quickly.

Our capability to access, extract, and analyze forest land data on a 'day to day' and 'special request' basis was severely hampered by our system. All required pertinent information was not being recorded because our system was cumbersome and our maps were becoming overcrowded. Descriptive information related to our maps was fragmented and not in a readily available form. Periodic maintenance of the maps, paper forms, and computer files was slow, conducive to errors, and costly. Security was jeopardized since all data could not be readily backed-up and stored off-site. Read/write time and processing speed on our computers was becoming a real hinderance as we developed more sophisticated applications and accumulated more data.

As computers became more pervasive and commonplace, information required increased simply because it was available and useful. Internally, within Canfor, we are expected to provide more information than a few years ago. Similarly, external requirements from the Ministry of Forests and other agencies has increased and is expected to become more onerous. After nearly a year of part-time research, we concluded our ability to record, store and analyze data could be vastly improved with the acquisition of a computerized GIS, a decision support and record keeping tool capable of helping us manage our timberlands more effectively. To this end, the Forest Inventory Section of Canadian Forest Product's Englewood Division began implementation of TerraSoft, a PC-based GIS, in December 1988.

Initial expectations of the system were:

1. The capability to construct digital maps to a standardized map base, with spatial forest data stored in levels that can be amalgamated to produce maps containing specific features;
2. The map base must be easily accessed for updating. Maintenance of our maps is an ongoing process. GIS must improve the quality, accuracy and speed of the updates;
3. The provision of a link between spatial and descriptive information. All map records and associated information must be integrated into one system. Much of the descriptive information linked to the map is very detailed and may not be displayed on the map but will be inherent in its structure. Therefore, maps must be produced to highlight areas where a specific management criteria is required,such as stands where ambrosia beetle, timber quality or planting stock survival history is of concern;
4. The integration of a database management system to store the descriptive information for the forest and biophysical inventory. The database and the spatial GIS data will be used for various analyses and projects. Major examples were:
   - Tree Farm License Management & Working Plans;
   - Harvest schedule plans (5, 10, and 20 year);
   - Legal & contractual obligations (Small Business Plan Analyses);
   - Forest and economic inventory;
   - Ecosystem classification;
   - Operability and environmental constraints;
   - Pre-harvest assessments;
   - Infrastructure data (roads, railway, bridges, etc.);
   - Cash flow constraints; and
   - Silvicultural implications.
5. The documentation of information learned from past activities. Historical data can be invaluable in forest management. Consolidation of data to evaluate past silvicultural treatments by such criteria as type of site preparation, location, species, year planted, site conditions, etc. Recording historical information is also beneficial in maintaining consistency and continuity of information into the future, despite eventual personnel and staffing changes. In addition, security is ensured since all data may be readily backed-up and stored off site; and
6. The integration of growth and yield models and a forest estate model.

Current Status and Capabilities

In January of 1991, two years have passed, and what have we achieved? We have produced what we call the 'fragmented forest' which gives us the ability to almost instantly access information across our 200 000 hectare TFL for over 120 variables. This fragmented forest consists of a 51 000 plus record database with 130 columns. In practice, the operator loads Terrasoft and calls up the TFL file. Last year, we converted our vector-processed map files into a new beta test version of Terrasoft which uses feature codes and a seamless database. Therefore, after calling up the TFL file the operator can simply zoom into the chosen area without the need to select which map he is in. Screen display is set by selecting from the menu shown in Table 1.

Positioning the cursor on a polygon can provide instantaneous access to information regarding that polygon. The range of information available is described in Table 2.

One of our original objectives for GIS was to be able to produce the data necessary for our TFL Management and Working Plan. This plan is produced every five years to document and justify our forest land management techniques. It addresses issues of current and long-term wood supply over a 200 year horizon, and various silviculture regimes, and habitat requirements. Aggregated data from the GIS-generated fragmented forest database was linked into FIBRPLAN,a forest estate simulation model. Growth and yield curve functions were assigned to FIBRPLAN, which was then used to test numerous management scenarios and to determine our Allowable Annual Cut. All data available from the 'fragmented forest' was not necessary for completion of the Management and Working Plan. However, we incurred the 'expense' of processing this extra information in order to have the flexibility to complete future projects.

The ability to produce Harvest Schedule maps for 5,10 and 20 year plans was an original expectation of the system. This has been achieved with added benefits, including:

- reducing the number of map bases at varying scales manually kept current by our draftsman;
- providing volume and grade information by cut block;
- production of colour E-size maps reproducable off site by a contractor using an electrostatic plotter for $30.00/ sheet; and
- utilizing thematic maps with supportive data to illustrate management goals or history

Throughout the start-up period, numerous maps were produced at varying scales for verification, as check plots and on special requests.

The issue of data security has been resolved. For example, the fire history of the Nimpkish Valley was mapped during the early 1950's, but only one copy of this invaluable map existed. The information was digitized in two days and is now retrievable at any time. Back-up tapes with all of our digital information is stored on- and off-site.

Maintaining and updating our maps in an efficient manner was another original goal. At this point, we start to get into issues that can be best understood if we briefly review our implementation procedures over the past two years.

Implementation

A successful GIS implementation must have a 'test bed' or pilot project. This is necessary to ensure any problems that may develop are caught early enough to be resolved with minimal cost. The topology or structure of the system, links to the database, layering techniques and report considerations are a few of the items that have to be determined. An efficient topology will reap long-term benefits. A pilot project is the logical place to assure this. A 25 000 hectare unit in the southern portion of our TFL was selected for our study. Since we lacked the expertise, equipment and personnel to load the information represented on our 1:15 000 scale planimetric inventory maps, we elected to contract out this phase; approximately eighty percent of the data we wanted digitized was contracted out. It was decided that certain features would be digitized on-site to force us to develop digitizing techniques, to start the training process for key personnel and to permit local operators familiar with the data to check the accuracy of linework while digitizing.

Throughout 1989 our major focus was on:

- creating a new staff position dedicated to Terrasoft;
- learning Terrasoft;
- refining the loading techniques with the contractor;
- deciding to load maps 'as is' without cleanup;
- confirming topology correctness through the assessment of the pilot project;
- resolving a technical problem with the vendor relating to raster overlay processing;
- becoming a beta test site for Terrasoft;
- using of R:BASE and FoxPro DBMS with Terrasoft; and
- completing the loading of the contracted portion of the project by December.

Throughout 1990 our major focus was on:

- installation of a 14 station Novell network;
- raster to vector processing;
- deciding in July to start full conversion to the new feature code seamless database beta version of Terrasoft;
- introductory training for digitizing and plotting;
- cleaning up 'dirty' data, edge tying, using the system to locate errors in data and having operator correct them;
- completing the digitizing of on-site data including:
    - ecosystem classification treatment units,
    - environmentally sensitive areas,
    - fire history,
    - cut blocks for 20 year plan,
- Timber License deletions,
- potential skyline logging areas,
- stand tending:spacing, fertilization,brushing and weeding, and
- commercial thinning.
- acquisition of contour data at a 150m interval for presentations;
- special request map plots;
- starting to resolve the issue of an inventory system versus an operational system; and
- the development of 18 major themes, culminating in the fragmented forest.

Map maintenance and updating procedures were developed 'on the fly', as issues occurred. We have always been aware of the problems associated with using an inventory based system for daily or operational functions. Problems were experienced in transferring linework from our 1:5 000 scale maps. This was predictable and will be resolved in 1991, most likely with a coordinate geometry interface. Considerable time was spent in correcting forest cover on the system. This was much easier to do in GIS. The tricky part was keeping track of all the changes and the order of occurence.

Goals for 1991

During 1991 our major emphasis will be toward developing:

- Timber License deletion applications;
- a timber cruise prediction system using GIS to assist in the development of Volume-Basal Area Ratio Tables;
- loading, via scanners, at 1:15 000 scale, our 20 000 hectare Forest License and develop to the TFL's GIS status;
- ambrosia beetle applications, in conjunction with a graduate student's thesis;
- training system users on three levels:
    - education at management level as to system capabilities;
    - occasional user for minor queries; and
    - key users in maintenance,plotting and analyses.
- updating the field atlas;
- adding landscape management information;
- the evaluation of existing wildlife habitat areas in relation to surrounding habitat opportunities;
- data verification;
- conversion to multiple features per object;
- creek and road network buffers; and
- moving towards coordinate geometry or another system to resolve the dual map base issue.

Conclusion

In conclusion, we stress the following as key points in the development process:

- Defining goals at outset of project;
- Staying focused on the goals. It is very easy to become involved in tangents;
- Be discrete! Data entry must be consistent and discrete; and
- Ensuring that everyone is aware of the steep learning curve for those involved in setting up the system. Full time dedication is required to become an accomplished user.

ACCESS	Accessibility Limits
CAMPSITES	Recreation campsites
COMPART	Compartment Boundaries
CONTOURS	Contours
CPERMIT	Cutting Permit Regions
CPERMIT2	Cutting Permit 2
CREEKS1	Class 1 Creeks
CREEKS2	Class 2 Creeks
CREEKS3	Class 3 Creeks
CREEKS4	Class 4 Creeks
ERRORFLAG	Error Flags for Vector Processing
ERRORFLAG2	Error Flags for Vector Processing
ESA	Environmentally Sensitive Areas
FIREHIST	Fire History
FIXFOREST	Processing Error Flag
FOREST	Forest Cover Boundaries
HYDRO	B.C.Hydro Lines
ISLANDS	Islands
LAKES1	Primary Lakes
LAKES2	Secondary Lakes
LAKES3	Lakes less than 1 ha.
LOGGING	Merged Logging 1,2,3, and 4
LOGGING1	In-Principle Planning
LOGGING2	Laid Out Logging Areas
LOGGING3	Logged Areas
LOGGING4	5 and 20 year Plan
NEATLINE	1:15 000 map line
OUTSIDE TFL	Areas outside TFL
PIP s	Photo Identifiable Points
PLOTS	Mature and Immature Plot Locations, Research Plots
POSTS	Corner Posts
RIVERS1	Primary Rivers
RIVERS2	Secondary Rivers
ROADS1	Highway
ROADS2	Primary Roads
ROADS3	Secondary Roads
ROADS4	Spur Roads
ROADS5	Proposed Roads
ROADS6	Road Beds
ROADS7	Railroads, active
ROADS8	Railroad Beds
SEASON	Seasonal Access Limits
SITE	Site Class
SKYLINE	Skyline Operational Areas
TENDING	Silvicultural Stand Tending
TENURE	Legal Tenure Boundaries
TENURED	Tenure Reverted to Crown
TFL	TFL #37 Boundary
THINNING	Commercial Thinning
TICKS	UTM and Latitude/Longitude
TRAILS	Recreational Trails
TRASH	Temporary Features
TREAT	Biogeoclimatic Zones with Treatment Units
WATERSHED	Watershed Boundaries
WILDLIFE	Deferred Wildlife Areas

Table 1. Screen Display Menu

FIELD	UNIT	EXPLANATION
Forest	12.44	Polygon reference number:Map 12;Polygon 44
P_area	4.60405	Polygon area in hectares
P_perim	1486.21574	Polygon perimeter in metres
P_x	623456.689	Label coordinate
P_y	5551547.587	Label coordinate
P_stat	OK	Vector processing error (ok,multi,unlinked)
L_x	623456.4	Link coordinate to label
L_y	5551547.5	Link coordinate to label
C_rot	45	Label rotation (0-360)
C_size	3	Label size (.1 - 255)
Query	CONDITIONAL	Database to CAD query
For_sort	12.044	Numeric sort of labels
Sps	HBC(Y)	Species Composition
Sps_major	HBC	Major Species Composition
Sps_minor	Y	Minor Species Composition
Gtype	HFP (5)	Growth type for estate and growth/yield model
Age	D	Age Class
Site	M	Site Class
Ht	2	Height Code
Year	0	Year of establishment for immature stands
Np	ALPINE	Non-productive
Cpermit	5	Cutting Permit Number
Setting	NW-32	Cut Block Number
Tenure	Crown	Crown, private, or crown grant
Tenured	C	Formerly private; currently reverted to crown
Tending	05M126	Silvicultural Stand Tending
ST_sps_maj	BCH	Code to link to Silvicultural Database
ST_sps_min	Y	Code to link to Silvicultural Database
ST_ave_dbh	20	Code to link to Silvicultural Database
Wildlife	NO	Deferred Wildlife Habitat areas
E.S.A.	Es1	Environmentally Sensitive Area
Season	S	Summer, Winter, or Intermediate access
Access	A	Access Line
Skyline	U	Skyline logging (up,down,aerial, or none)
Treat	Cx	Biogeoclimatic Zone with sub-treatment units
Volink	SD2LHBCY	Derivation of volume code
Volcode	69	Inventory volume code
T_vol_ha	678.000	Total volume per hectare
Fir_vol	0.000	Fir volume per hectare
Ced_vol	197.000	Cedar volume per hectare
Bal_vol	252.000	Balsam volume per hectare
Spr_vol	0.000	Spruce volume per hectare
Hem_vol	153.000	Hemlock volume per hectare
Hm_vol	20.000	Mountain hemlock volume per hectare
Y_vol	56.000	Yellow cedar volume per hectare
Wp_vol	0.000	White pine volume per hectare
Pl_vol	0.000	Lodgepole pine volume per hectare
Fir_a	0.000	Volume per hectare Fir, grade A
Fir_b	0.000	Volume per hectare Fir, grade B
Fir_c	0.000	Volume per hectare Fir, grade C
Fir_d	0.000	Volume per hectare Fir, grade D
Fir_f	0.000	Volume per hectare Fir, grade F
Fir_h	0.000	Volume per hectare Fir, grade H
Fir_i	0.000	Volume per hectare Fir, grade I
Fir_j	0.000	Volume per hectare Fir, grade J
Fir_u	0.000	Volume per hectare Fir, grade U

Table 2. Summary of Available Polygon Information

Fir_x	0.000	Volume per hectare Fir, grade X
fir_y	0.000	Volume per hectare Fir, grade Y
Ced_d	0.000	Volume per hectare Cedar, grade D
Ced_f	0.000	Volume per hectare Cedar, grade F
Ced_h	23.000	Volume per hectare Cedar, grade H
Ced_i	0.000	Volume per hectare Cedar, grade I
Ced_j	0.000	Volume per hectare Cedar, grade J
Ced_k	0.000	Volume per hectare Cedar, grade K
Ced_l	0.000	Volume per hectare Cedar, grade L
Ced_m	66.000	Volume per hectare Cedar, grade M
Ced_u	45.000	Volume per hectare Cedar, grade U
Ced_x	56.000	Volume per hectare Cedar, grade X
Ced_y	7.000	Volume per hectare Cedar, grade Y
Bal_c	19.000	Volume per hectare Balsam, grade C
Bal_d	0.000	Volume per hectare Balsam, grade D
Bal_f	0.000	Volume per hectare Balsam, grade F
Bal_h	34.000	Volume per hectare Balsam, grade H
Bal_i	67.000	Volume per hectare Balsam, grade I
Bal_j	59.000	Volume per hectare Balsam, grade J
Bal_u	40.000	Volume per hectare Balsam, grade U
Bal_x	33.000	Volume per hectare Balsam, grade X
Bal_y	0.000	Volume per hectare Balsam, grade Y
Spr_c	0.000	Volume per hectare Spruce, grade C
Spr_d	0.000	Volume per hectare Spruce, grade D
Spr_e	0.000	Volume per hectare Spruce, grade E
Spr_f	0.000	Volume per hectare Spruce, grade F
Spr_g	0.000	Volume per hectare Spruce, grade G
Spr_h	0.000	Volume per hectare Spruce, grade H
Spr_i	0.000	Volume per hectare Spruce, grade I
Spr_j	0.000	Volume per hectare Spruce, grade J
Spr_u	0.000	Volume per hectare Spruce, grade U
Spr_x	0.000	Volume per hectare Spruce, grade X
Spr_y	0.000	Volume per hectare Spruce, grade Y
Hem_d	0.000	Volume per hectare Hemlock, grade D
Hem_h	5.000	Volume per hectare Hemlock, grade H
Hem_i	45.000	Volume per hectare Hemlock, grade I
Hem_j	11.000	Volume per hectare Hemlock, grade J
Hem_u	33.000	Volume per hectare Hemlock, grade U
hem_x	55.000	Volume per hectare Hemlock, grade X
Hem_y	4.000	Volume per hectare Hemlock, grade Y
Hm_d	0.000	Volume per hectare Mountain Hemlock, grade D
Hm_h	0.000	Volume per hectare Mountain Hemlock, grade H
Hm_i	5.000	Volume per hectare Mountain Hemlock, grade I
Hm_j	0.000	Volume per hectare Mountain Hemlock, grade J
Hm_u	9.000	Volume per hectare Mountain Hemlock, grade U
Hm_x	6.000	Volume per hectare Mountain Hemlock, grade X
Hm_y	0.000	Volume per hectare Mountain Hemlock, grade Y
Y_d	0.000	Volume per hectare Yellow Cedar, grade D
Y_f	0.000	Volume per hectare Yellow Cedar, grade F
Y_g	0.000	Volume per hectare Yellow Cedar, grade G
Y_h	0.000	Volume per hectare Yellow Cedar, grade H
Y_i	5.000	Volume per hectare Yellow Cedar, grade I
Y_j	0.000	Volume per hectare Yellow Cedar, grade J
Y_k	0.000	Volume per hectare Yellow Cedar, grade K
Y_l	0.000	Volume per hectare Yellow Cedar, grade L
Y_m	0.000	Volume per hectare Yellow Cedar, grade M
Y_u	22.000	Volume per hectare Yellow Cedar, grade U

Table 2. Summary of Available Polygon Information, continued

Y_x	24.000	Volume per hectare Yellow Cedar, grade X
Y_y	5.000	Volume per hectare Yellow Cedar, grade Y
Pw_d	0.000	Volume per hectare White Pine, grade D
Pw_h	0.000	Volume per hectare White Pine, grade H
Pw_i	0.000	Volume per hectare White Pine, grade I
Pw_j	0.000	Volume per hectare White Pine, grade J
Pw_u	0.000	Volume per hectare White Pine, grade U
Pw_x	0.000	Volume per hectare White Pine, grade X
Pw_y	0.000	Volume per hectare White Pine, grade Y
Pl_h	0.000	Volume per hectare Lodgepole Pine, grade H
Pl_i	0.000	Volume per hectare Lodgepole Pine, grade I
Pl_j	0.000	Volume per hectare Lodgepole Pine, grade J
Pl_u	0.000	Volume per hectare Lodgepole Pine, grade U
Pl_x	0.000	Volume per hectare Lodgepole Pine, grade X
Pl_y	0.000	Volume per hectare Lodgepole Pine, grade Y

Table 2. Summary of Available Polygon Information, continued

GIS'91

Symposium

Vancouver
British
Columbia
February 1991

From Research to Production: Using GIS and Image Processing to Map Vegetation on 30 Million Acres of National Forest Lands

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Abstract

In 1988, the Pacific Northwest Region of the Forest Service initiated a program to build a geographic information system (GIS) database for all National Forests in the Region. Development much of the data base has been contracted to Pacific Meridian Resources.

Up to 14 data layers are being built, depending on the local nature of the National Forest. The layers include slope, aspect, elevation, location of research plots, hydrology, flight line map, crown closure, species, stand structure, tree size, old growth, and vegetation type polygons . An area of approximately 30 million acres is being mapped.

Pacific Meridian has developed sophisticated production methods for the creation and accuracy assessment of these GIS databases. The methods include the integration of image processing, GIS, and statistical software. Methods and results will be discussed. Emphasis will be placed on the issues inherent in transferring technologies from research to production.

GIS'91

Symposium

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GIS in Forestry Taxation in Finland

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Abstract

The total forest area in Finland amounts to 20 million hectares, including 410 000 ha in private forest holdings. Forestry taxation is based on the income of an average yield base estimated from the standing forests. As a public policy to promote good silviculture, the forest owners may reduce some of their costs by having some areas declared tax-free. Updating all of this data with an analog mapping system is time and labour intensive, so GIS is seen as a very important advance.

Introduction

The GIS system used in Finnish forest taxation is called VENLA. It is built on a GIS system called FINGIS, which uses an ORACLE database. It controls forestry taxation data and supplies the data to the databases for taxation calculations. VENLAs input sources are forest classification groups; the updating sources are mainly forestry related authorities. More and more of the data is entered digitally. By the end of 1991, the area controlled by VENLA will be about 1500 mapsheets with a database of about 1800 megabits. VENLA has given us remarkable improvements in forest classification and updating. The economic estimates show it to be profitable.

The Finnish Forest Taxation Method

Finland possesses 20 million hectares of forests, 80% of which are owned by private persons. There are about 410 000 private forest holdings mostly devoted to farming.

The taxation is determined by the income of an average yield base. The average yield is estimated from the standing forests. Every piece of forest is classified, mapped and divided into four tax classes, as well as waste land.

Every tax class is estimated to yield a certain amount of stemwood. This information is used to calculate the annual average yield of wood per forest holding, in cubic metres.

The tax rate follows the average market price. By observing good silviculture practises, forest owners may receive an exemption or rate reduction for certain land use classes; such economic trade-offs are expected to partially compensate for the cost of these silviculture practises. The tax-free areas are mostly young forest. This program has worked well. There are about 2 to 3 million hectares of forest outside the taxation base. Since the total tax remains the same, the forest owners who participate gain an advantage over those who do not.

The site quality of forest land on a holding is based on an on-site mapping. This results in the assignment of a tax classification. The different areas of land usage are surveyed and the forest land is classified by the use of Cajander's forest site types. The tax class polygons are drawn on a terrain map, from which they are digitized.

The National Board of Taxation uses 7 classification groups, arising from the usage of the National Board of Survey and 5 private enterprises. These are based on three different GIS systems. In the transmission of data, the VENLA format is used.

The need to control geographic information in forest taxation is critical. The data is rapidly changing: the establishment of new boundaries, areas, roads and fields, the transition of forest plantations to unproductive wastelands are constant occurrences. Tax-free areas are also large and vary with time.

Updating all of this data by analog mapping takes a lot of time and infrastructure. Neither the money nor the personnel required are easily found. With age, the quality of the tax classifications drifts from reality and society loses tax revenues. From this point of view, the use of GIS in forest taxation is a step forward.

The VENLA GIS System

VENLA's role is to organize the forest taxation data so that it is easily updated and readily available. VENLA also has extensive checking programs, which analyze all input data for completeness and validity.

VENLA consists of two parts: FINGIS, the National Board of Survey's GIS and the ORACLE database. All taxation calculations are conducted by VENLA accessing the ORACLE database. The planning tool is Case Dictionary.

VENLA organizes data on different levels of elements, such as boundaries for real estate, road and electric nets, forest tax classes, forest price zones inside a community and tax free forest lands.

VENLA generates different tables for map production and data quality assessment. Transmission tables, which update the real estate database, are created from these. An update to VENLA prompts an update to the real estate database. VENLA does not retain all of the real estate database, as parts of it are not relevant to forest taxation and are easily recovered from the real estate database, if needed. The real estate database will have a simultaneous updating system, except for those communities still outside VENLA, which will require manual preparation. The calculations for real estate and forest taxation both use the real estate database.

Initially, the updating and the databases were centralized. As more communities are included, these activities will be decentralized to the various county tax centres. The taxation databases are being decentralized at present. The centres maintain an on-line network with each other, so the VENLA database is available everywhere.

The classification groups produce the basic input for VENLA. They receive additional input approximately every ten years. Normal updating input comes mainly from the National Board of Survey, the Private Forest Extension Service, forest owners and courts.

Presently, real estate boundaries come from the National Board of Survey maps but will be digitized in the future. The tax-free areas are received from the National Forest Extension Service as digital data and they contain the cordinates of the reference points, but not their boundary arcs. The digital updating of the boundaries of tax-free areas makes it possible to control them. Because some of the boundaries overlap and some tax-free areas cover wasteland without control, VENLA will detect the lost tax revenues. This alone will cover the costs of implementaiton.

The software costs were approximately $100 000 US. The widespread availability of FINGIS forms the main structure of VENLA and reduces the initial cost. The marginal costs for VENLA's own hardware will cost $100 000 US in the first centralized phase and $400 000 US in the second decentralized phase.

VENLA needs normal hardware for updating and digitizing. In the centralizing phase, the hardware required consists of:

a MicroVax II for processing the data;
2 to 3 graphic tables;
2 to 3 digital boards;
a plotter; and
a dot-matrix printer.

After decentralization, five centres will be added, with each centre requiring the equipment described above.

With the co-operation between the authorities, it will become easier to input new material into the system. The National Board of Surveys has agreed that it will give priority to digitalize those communities which have the greatest need for forestry tax classification. This has worked well. There are also projects to promote the wider use of GIS systems, which are organized by the different authorities.

VENLA Coverage: Present and Future

One of the main problems with GIS systems is the organization of the input data. We have now organized 50 communities out of 450. Their area is about 2 million hectares and the size of database is about 1200 megabits. The annual addition will be about 25 communities, adding 1 million hectares and 600 megabits annually.

In the future, VENLA will contain all urban as well as rural real estate records. It will then be useful to provide access to VENLA at the municipal level. Then VENLA will supply a number of lines of input material to the real estate database.

The economic advantage of VENLA is readily seen by comparing it to the manual method for the 1986 survey.

	Manual Method	Possible Savings
Terrain surveys	0.97*	0 %
Map plotting and area calculations	0.83	50 %
Surveying the owners, info, equipment, office, etc.	0.22	25 %
Maps, aerial photographs	0.17	15 %
Annual updating	0.28	50 %
Sum	2.47 $US	0.64 $US
Sum %	100 %	25 %

*in millions of $US

VENLA will save resources, particularly if they are used to expand the classification, as taxes will rise about 15 %.

Marginal costs and marginal incomes from taxes stated in discounted values from different periods, in millions of $US.

Time, in years	Marginal Incomes $US	Marginal Costs $US
5	7.2*	3.2
15	35.5	6.2
25	61.9	7.1

Discounting percentage, 8 %

VENLA seems to be a very profitable investment.

Feedback on the Development Process

The development of VENLA addressed not only technical and economic problems, but also administrative difficulties in the National Board of Taxation. With numerous other GIS applications pending, the actual benefits and costs of this system are of major interest.

The development took three years. One basic study was done in 1986 to compare the different systems then available. The long time-lag created extra problems as needs, surroundings, laws and ADP applications changed.

It seems that our model has encouraged the National Board of Forests, the National Private Forest Extension and the National Board of Surveys to organize their own GIS projects, which largely resemble VENLA.

The National Board of Taxation's ADP office was so busy in integrating the ORACLE relational database into the taxation calculations that they were unable to provide much assistance.

In hindsight, the VENLA system manager should have been a principal participant in the process from the very beginning.

We are nearing the end of the project. We have effective tools to control and update the data for the forest taxation. Revisions of the aging forest tax classifications will be easier in the future.

Concurrent Session 2

Techniques - Spatial Data

The Effect of Spatial Data Variability on Decisions Reached in a GIS Environment

The Integration of Resource Inventory Field Data and Thematic Spatial Databases

Integration of Spatial Analysis Technologies for Forestry Applications

GIS'91

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The Effect of Spatial Data Variability on Decisions Reached in a GIS Environment

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Abstract

Values generated from spatial databases will play increasingly important roles in the future applications of GIS in natural resources. Generated values, such as areas of polygons or distances between features, will be used quantitatively as inputs or multipliers in integrated decision models. However, what are the statistical properties or characteristics of areas and distances computed in a GIS? Without information of this type, managers will not be able to critically evaluate the results of decision models. They will be unable to place confidence bounds on the results of decision models unless they can first place confidence bounds on the values generated from the spatial data in the GIS.

Methods have recently been developed to characterize the statistical properties of areas and distances computed in arc-node GIS. An example is presented which illustrates these methods, and which demonstrates the impact of area variability on a simple valuation model. The success of future applications of GIS in an integrated, decision-making context will depend upon a thorough understanding and a complete characterization of the spatial data itself.

Introduction

Forest resource management is, by its nature, concerned with spatially occurring phenomena. Data collected and used by resource managers are associated with earth locations. Decisions made by forest managers are typically implemented at specific sites. It comes as no surprise, therefore, that foresters have exhibited a great deal of interest in Geographic Information Systems (GIS).

While most foresters using GIS recognize that their data and results contain errors, this acknowledgement is not communicated to users of these analyses unless specific statements are made as to accuracy and precision. Users of forest resource reports and inventory estimates may be quite accustomed to statements about accuracy and precision. These statements may come in the form of confidence intervals or standard deviations, and acknowledge the probabilistic nature of the figures reported. However, this stochastic treatment of the attributes of spatial phenomena has not been extended to a stochastic treatment of the location of spatial phenomena. Recent GIS literature and studies have begun to call attention to this serious shortcoming.

An example of what is missing from GIS accuracy studies is a quantification of the variability of area estimates. Area estimates are pervasive in the data used in resource management decisions. Yet when area figures are printed on a map or in a report, there is rarely any indication that these are estimates, and are therefore subject to bias and imprecision. When resource variables such as timber volume are expressed on a per-acre or per-hectare basis, the implication is that these numbers will eventually be multiplied by an estimate of area. Therefore, area errors will have a multiplicative effect in many analyses, and an error statement becomes important.

The application of GIS in natural resources would be greatly enhanced by an explicit recognition of the errors in digital spatial databases and a more thorough understanding of the impacts of these errors on the resource management decisions which rely upon GIS analyses. First, since forestry GIS databases typically contain information from a variety of sources, scales, and accuracies, it would be helpful to incorporate information regarding the quality of the source data into the database itself. Next, once information is available regarding the variability of source data, or if assumptions can be made about this variability, a technique is needed to translate information about positional variability into information about area or distance variability. For example, a procedure to derive confidence intervals on the area of timber stands, given a map and some statement or assumptions about its locational precision, would be valuable. Such a procedure should be statistically sound, capable of being automated and included in typical GIS analyses, and sufficiently flexible to accommodate different assumptions about source data variability.

Models of spatial error in GIS contribute to a better understanding of the relative magnitude of spatial errors and attribute errors. If estimates of area are found to be more variable than estimates of per-acre values, for example, a different allocation of inventory resources may be in order: more on deriving area estimates and less on per-acre value estimates. On the other hand, if area estimates are found to be less variable than previously assumed, perhaps more confidence in GIS analyses would be justified.

Several recent efforts have produced models of polygon area variance based upon assumptions or evidence about the locational variability of point coordinates. Bondesson (1986) derived estimates of the standard error of areas obtained by traversing a compartment. He assumed normal errors in bearings and distances, and assumed that errors at adjacent points were uncorrelated. Using these assumptions, and standard surveying formulas for computing area, he obtained estimates for area variability.

Chrisman and Yandell (1988) developed a model to describe the bias and precision of area estimates based upon X- and Y- coordinates. They assumed independent and identically distributed coordinate errors at well-defined points representing the vertices of a polygon. They reported that the resulting area estimates were unbiased, with variance equal to a function of the coordinates. While their results may be applicable to cadastral data, the reliance on independent errors and well-defined points may limit the usefulness of their model for natural resources data, which are less likely to exhibit the assumed characteristics.

Griffith (1989) reported several formulae for area variance based upon a variety of assumptions regarding autocorrelation of errors. The matrix notation he used resulted in considerable simplification in the variance equations. Prisley (1989) developed a stochastic model for area variance based on the arc-node data structure, again using assumptions about point location variability and correlation. All points in a given arc were assumed to have similar error characteristics (standard deviation of X-Y location and serial correlation of errors at adjacent points). Thus, locational variability was described by two parameters (σ and ρ) for each arc in a map. Basing assumptions upon arc attributes allowed consideration of covariance of errors in area of adjacent polygons, which is critical in many GIS applications. It is this latter model which is used in this paper. We will not reproduce the equations in this report for brevity; for more detailed explanations of the derivation process and the final variance equation forms, see Prisley, et al (1989).

Polygon Area Errors - Example Applicaiton

An example application of the polygon area variance expression was performed to demonstrate its utility. The application consisted of an analysis of the variability of value of a tract of forested land, due to the variability of area estimates. As noted by Meyer (1963), variability of area estimates is often ignored when total volume (or value) estimates are calculated. The analysis conducted here was meant to demonstrate how area variability can be accounted for in performing such routine tasks as volume or value summaries. The variability of total volume (value) consists of two parts; that due to volume determination, and that due to area determination. The former is commonly considered using a standard error estimated from the sample of plot volumes, but will be ignored here in order to concentrate on the latter. However, both components could be considered jointly.

This analysis was performed using data from a timber value analysis of a tract of land in the southeastern U.S. The subject parcel will be referred to as the Webster tract. The 219-acre tract consists of five stands, two of which are non-forested. The remainder include a 94-acre stand of upland hardwood, a 79-acre stand of bottomland hardwood, and a 21-acre stand of loblolly pine planted in 1961. These three stands were cruised using a systematic sample of variable-radius plots (BAF 10) on a 4-chain by 5-chain grid.

After obtaining a survey of the tract boundary, 70mm natural color aerial photographs of the tract were interpreted to delineate stand boundaries. The photo scale was 1:15 840, or 1 inch to 20 chains. The map was digitized, and point coordinates were extracted for input into computer programs which calculated polygon area variance and covariance. From the inventory data, pine and hardwood pulpwood and sawtimber volumes were calculated using appropriate volume equations. Using current stumpage prices as reported by Timber-Mart South (1989), and volumes per acre from the cruise, a per-acre timber value was calculated for each stand (Table 1). The total timber value is obtained from:

$$V = \sum_{i=1}^{n} v_i a_i$$

where: V = total timber value
v = timber value per acre for stand i
a = acres in stand i
n = number of stands in the tract

The variance of tract value (neglecting variance in value per acre) is:

$$\mathrm{Var}(V) = \sum_{i=1}^{n} v_i^2 \cdot \mathrm{Var}(a_i) + 2 \cdot \sum_{i<j} v_i v_j \cdot \mathrm{Cov}(a_i a_j)$$

The variance and covariance terms were obtained using the expressions described in Prisley, et al (1989), under 9 different sets of assumptions about locational errors: three assumed standard deviations (σ) for X-Y location errors, and three levels of autocorrelation (ρ) between errors at adjacent points. The assumptions began with three choices for which were expected to encompass the range of realistic values; these were 0.3, 0.6, and 0.9. A recent survey of the tract boundary indicated a standard deviation of error in monument location of approximately 2 feet. Thus, all arcs on the tract boundary were assigned a standard deviation for points of 2 feet. Even under the best possible conditions, the accuracy of timber stand mapping cannot be expected to be better than the width of the line with which stands are delineated; therefore, the lowest standard deviation used for point location errors was 25 feet (a 0.5mm line at a scale of 1:15 840 represents a band 26 feet wide on the ground). A more realistic value was estimated to be about 50 feet, and an extreme value of 75 feet was included. Using the estimated values per acre for each stand and variances and covariances of polygon areas, the variance of total tract value was obtained for each of the nine sets of assumptions.

Area Variance Results

The results of the variance calculations for timber value are presented in Table 2. Variances ranged from approximately 3% to 15% of total timber value. These values are larger than might be expected, especially at high and . Increasing or will increase area variability in a linear fashion. The choice of appears to have a greater influence on the resulting variability of value than does the choice of .

Stand	Description	Acres	Pine tons/ac.	Hardwood tons/ac.	Timber Value $/ac.
1	Open Scrub	2.3	0.0	0.0	0.00
2	Upland hardwood	94.1	2.7	50.5	211.68
3	Bottomland Hardwood	78.9	0.0	92.0	597.57
4	Loblolly pine (1961)	21.2	74.0	6.0	443.69
5	Abandoned field	22.4	0.0	0.0	0.00
	Total :	218.9		Average: 348.97	

Table 1. Timber volumes and values for the Webster tract.

sigma used for internal arcs		rho=0.3	rho=0.6	rho=0.9
25	Std.Dev.:	2208.7	3110.5	3805.9
	C.V.:	2.89%	4.07%	4.98%
50	Std.Dev.:	4424.9	6228.5	7566.0
	C.V.:	5.79%	8.15%	9.90%
75	Std.Dev.:	6679.4	9377.2	11455.9
	C.V.:	8.74%	12.27%	14.99%

(*) Total timber value was estimated to be $76,424.

Table 2. Standard deviation and coefficient of variation of total timber value estimates1 for the Webster tract under nine assumptions of sigma and rho for point location errors.

Under the set of assumptions which seem most realistic (σ=50, ρ=0.6), the standard deviation of value was 8% of the estimated total timber value.

While this analysis was a cursory demonstration of an application of the variance formulae, it indicates that the variability of summary estimates due to imprecision in spatial data can be significant. The assumptions used here were meant to be only approximations; more intensive analysis of the mapping process could produce more reliable estimates of σ and ρ (see Chrisman, 1982). However, even such approximations as used herein can be useful for comparative purposes. For example, suppose two tracts of land are being considered for acquisition, and only one will be purchased. If the two are mapped and cruised in similar manners, comparisons of variability can be made under a variety of assumptions. If the values of the tracts are similar, yet have widely different variances, the tract with lower variance of value would appear to present less risk, and would be the desirable choice. Precise and accurate knowledge of σ and ρ is not necessary in such circumstances.

Overall Forest Survey Precision

A forest survey is an evaluation of the extent and condition of forest resources. It may take the form of a timber cruise on a specific sale area, a region-wide inventory of growing stock, an evaluation of wildlife habitat in a given management area, or many other such applications. In general, though, a survey measures some attribute, or value, on a per-unit-area basis, and delineates the areas to which these values are applied. An interesting extension of the analysis presented here would be to consider both components of survey variability; that due to variance of per-unit-area estimates, and that due to spatial imprecision. In an example presented by Schumacher and Bull (1932), the standard error of total volume can be seen as consisting of two terms:

$$SE^2_{TV} = SE^2_V * A^2 + SE^2_A * V^2$$

where: SE_{TV} = standard error of total volume estimate
SE_V = standard error of volume per acre estimate
A = area in acres
SE_A = standard error of area estimate
V = volume per acre

This equation can also be expressed in terms of relative standard errors:

$$SE_{TV\%} = SE_{V\%} + SE_{A\%}$$

where: $SE_{X\%} = SE_X / X = CV_X$ (coefficient of variation of X)

While this example only considered area variability, the above expressions could be used to account for both variance components. Clearly, area variance is as important in relative magnitude as variance in per-unit-area value since both have a weight of one in the equation for total variance.

Although much effort has been expended attempting to improve precision of per-unit-area estimates, very little has gone into identifying and improving map precision. Suppose that the variation of the per-unit-area estimates is approximately 10% (which is a frequently reported value). It is thus reasonable to assume from our results that the area variance is often just as large, and thus contributes as much to total survey variance.

Knowledge of the relative contribution of per-acre volume variance and area variance toward total variance might suggest where effort might best be directed to increase precision. More samples might be taken to reduce per-acre volume variability, or more detailed mapping, through better equipment, larger-scale photography, or better ground control, would likely reduce area variability. Consequently, inventory resources could be directed where they would be most efficient in terms of variance reduction.

Conclusion

It is not the intent of the authors to imply that area variance is always a critical component of the decision process. It is, however, ignored virtually all of the time as a contributor to forest survey error. As we use GIS more for decision-making and less as a map display device, the variability of values computed in the GIS will become more important. We have demonstrated that it can be a significant factor, and may be larger than most users realize. There are currently several published models to describe area variability based upon GIS data. While some refinement of these models is desirable, it is important that these models find their way into the GIS software commonly used by resource managers. Only then can decision makers benefit from a more thorough understanding of the reliability of GIS data, products, and estimates.

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The Integration of Resource Inventory Field Data and Thematic Spatial Databases

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Abstract

Resource inventory field data is the foundation of site-specific attribute information that describes thematic spatial databases stored in geographic information systems (GIS).

Resource inventory data is frequently summarized to estimate the average characteristics of thematic types such as forest covertypes, land-use types, and harvest units. The use of an average vegetation type or a harvest unit summary information often lacks the detail and accuracy available from the analysis of the individual inventory plot data. GIS enables the use of site-specific plot data to develop more accurate and reliable estimates for portions of vegetation types or harvest units.

Other benefits of the integration of resource inventory plot data are the integration of resource models, such as growth models, that require inventory data and the development of site-specific detailed reports and summaries, such as tree and log frequency distributions by size class and species.

Examples of the integration and use of detailed resource inventory field data with thematic type information are presented and contrasted with the use of less detailed type averages.

Introduction: Natural Resource Information Needs

Resource managers are faced with many significant management decisions that involve a variety of issues and disciplines, some of which concern biological and environmental issues and regulations while others concern economic and financial issues related to efficiency, maturity, and profitability. The resource management decisions that must be made are not new and have tested the judgment of professionals for years. What has changed is that the decisions have increased in complexity. As a result, information needs have also increased. For example, the concept of sustained yield is no longer limited to the production of timber, but also includes wildlife, soil, water, and other benefits derived from the forest ecosystem.

To address growing information needs and assist the decision making process, resource managers have been developing, implementing, and applying geographic information systems (GIS).The information that was formerly maintained on paper maps and in large, bulky tabular folders and printouts has now been converted to a format that enables the satisfaction of many of our past information needs. There are also examples, such as network analysis, intervisibility studies, and the integration of satellite image classification processes and GIS databases, that demonstrate that the use of GIS also enables the development of new themes of information and the application of new types of analysis that were previously impossible.

The inclusion of resource inventory data as a component of a GIS can improve the resource management decision making process. This type of data enhances the ability to develop and update thematic information and supports more detailed and specific resource information applications.

Resource Inventory Data Structure and Information Development

Thematic databases, such as those that describe vegetation or timber harvest plans, are an attempt to describe area differences that we determine to be significant and identifiable. These databases are often developed by delineating type boundaries on aerial photos, maps, or imagery and then by estimating the type attributes or characteristics by evaluating and summarizing resource inventory field data that has been collected within the delineated areas. The thematic attributes that were developed and stored to describe individual types are generalized or averaged information, such as the vegetation type attributes shown in Table 1.

Resource inventory field data or plot data is the foundation of the site-specific attribute information that is processed to describe thematic type information. This field data may cover very large areas, contain hundreds of thousands of individual tree measurements, and result in very large databases. For these reasons and the fact that previously measured plots may not have been located accurately enough to be certain of their location, resource inventory plot databases are not normally maintained on a GIS.

However, it is possible to store the locations of the individual resource inventory plots in a GIS. The key to this graphic database is the accurate location of the field plots. Field sampling techniques should be designed to include standardized methods for locating and measuring plots. For example, plots should be evenly spaced along lines of a known direction, but plots should be offset if they are going to fall on the edge between two distinct vegetation types, since plots will be allocated in their entirety to a vegetation unit, it is important that 'mixed' plots are not created by measuring plots that include more than one vegetation type. Therefore, inventory crews must be knowledgeable about the vegetation they are surveying. They must also be aware of their field location and note geographic features, such as road or stream crossings, that may be used to reference their location. Plot locations should be pricked on aerial photos or spatially referenced using some other means, such as global positioning systems, to facilitate the mapping of the field plots. The plot locations, each with its own unique plot identifier, are then input into the plot location graphic database in the GIS.

The resource inventory information associated with each field plot is stored in two tables in the relational database. The individual tree measurements, such as species code, dbh, log height, and percent live crown, are stored as a row in a **tree_detail** table. Each row of this table also contains the unique plot identification number that is included in the graphic database. The plot attribute information is generated by processing the **tree_detail** table with the appropriate plot summarization software. The attributes of each plot, such as volume, basal area, and number of stems for each major species group expressed on a per unit area basis, are stored in a row of the **plot_detail** table and are also keyed to the unique plot identification number.

By storing the resource inventory plot data as a data theme in the GIS, resource managers may use spatial analysis capabilities to relate the resource inventory information to a thematic level of interest, such as the vegetation theme. The vegetation theme is described by two

Table 1 Vegetation Database Attributes

stand_id	[19042503]
type_code	[R3D]
vegetation_class	[YOUNG GROWTH MATURE]
acreage	[208.4]
age	[70]
rwd_vol	[26.8]
fir_vol	[2.3]
pine_vol	[0.2]
conif_vol	[29.3]
hard_vol	[0.1]
pct_conifer_vol	[99.66]
base_year	[1920]
data_source	[1987 GRS CRUISE]

site	[4]	scheduled harvest	[1995]
basal area/acre	[145]	average dbh	[15.9]
density index	[130]		

databases: a graphic database that contains the type delineations or linework that define the boundaries of the thematic types and a **vegetation_detail** table in the relational database that contains the attributes that describe the vegetation types and are keyed to unique vegetation unit identification numbers. After spatially relating the plot data and the vegetation data, the resource manager 'knows' which resource inventory plots are contained in specific vegetation types or units.

The result of the spatial analysis application is a new database table, **plot_by_veg**, that includes the unique plot identification number and the unique vegetation unit identification number in which the plot is located. This table provides the information necessary to selectively join the thematic vegetation information and the resource inventory plot information on the basis of their spatial relationship. Summaries of inventory plots by vegetation type are accomplished quite easily using database report capabilities. The summarized plot information is then loaded as an updated row in the **vegetation_detail**. This process facilitates the development and updating of vegetation type information. As new areas are inventoried or type lines are modified, the vegetation database is updated and related to the resource inventory plot database. A new **plot_by_veg** table is generated and new or updated vegetation type information is developed and loaded into the **vegetation_detail** database. The relationship of these tables is shown below in Figure 1.

vegetation_detail table: veg_id, (vegetation type attributes)
plot_by_veg table: plot_id, veg_id
plot_detail table: plot_id, (plot attributes)
tree_detail table: plot_id, (tree attributes)

Figure 1. Database Table Relationships

The resource inventory data information also may be used to develop attributes of other thematic types, such as timber harvest units, by spatially relating the plot locations to the timber harvest plan areas, generating a **plot_by_thp** table, and by summarizing the **plot_detail** information of the plot locations specific to each timber harvest plan of interest.

Information Development Limitations

For the past fifteen years, I have worked with natural resource databases, GIS, and the development of resource information. My experience also includes years of monitoring resource estimates and projections and comparing the estimates with actual experience. I do not believe that the use of thematic databases adequately satisfies our information needs, because we do not always develop the 'best' information available since we often limit our work to generalized information.

The use of generalized thematic databases has several limitations and drawbacks when compared to an alternative approach that includes the integration of the resource inventory field data as a separate and distinct level of information in the GIS database. These drawbacks include less reliable estimates and projections, degradation of the database as it is updated to reflect change due to stand growth and harvest operations, and the inability to develop some of the detailed, site-specific stand descriptions based on individual tree characteristics and models.

Thematic Database Accuracy and Reliability

The variance between our estimates and our experiences is quite likely higher than the variance derived from resource inventory plot data when we limit our analysis to the generalized data we maintain in thematic databases. Higher variance results because the generalized thematic information is one average value that represents all the acres of a thematic type. When estimates are developed for a particular area of interest that contains a portion of the entire type, more reliable and accurate estimates may be developed by summarizing the resource inventory data collected within the boundaries of the specific area of interest.

Consider the vegetation types shown in Figure 2.

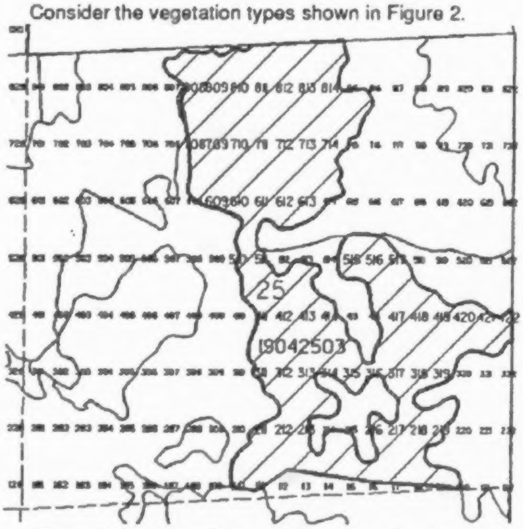

Figure 2. Vegetation Types and Inventory Plot Locations

One vegetation type, Unit 19042503, has fifty-two resource inventory plots within its type boundaries. Summarization of the fifty-two inventory plots indicates an average volume per acre of 29.2 Mbf/acre, as shown in Table 2. This attribute is an appropriate estimate of the average volume for all the acres of this type.

Table 2

INVENTORY PLOT SUMMARY FOR VEG UNIT: 19042503

52 PLOTS 208.4 ACRES

PLOT ID	RWD VOL	FIR VOL	PINE VOL	HDWD VOL	TOTAL VOL
1904250110	36.0	4.5	.0	.0	40.5
1904250111	28.0	.0	.0	.0	28.0
1904250211	32.0	4.5	.0	.0	36.5
1904250212	40.0	.0	.0	.0	40.0
1904250213	36.0	4.5	.0	.0	40.5
1904250216	40.0	.0	4.5	.0	44.5
1904250217	32.0	4.5	.0	.0	36.5
1904250218	24.0	4.5	4.5	.0	33.0
1904250219	28.0	.0	.0	.0	28.0
1904250311	32.0	.0	.0	.0	32.0
1904250312	24.0	4.5	.0	.0	28.5
1904250313	28.0	4.5	.0	.0	32.5
1904250314	32.0	.0	.0	.0	32.0
1904250315	24.0	4.5	.0	.0	28.5
1904250316	20.0	4.5	.0	.0	24.5
1904250317	24.0	.0	.0	.0	24.0
1904250318	32.0	4.5	.0	.0	36.5
1904250319	28.0	4.5	.0	.0	32.5
1904250411	32.0	4.5	.0	.0	36.5
1904250412	20.0	4.5	.0	.0	24.5
1904250413	24.0	4.5	.0	.0	28.5
1904250414	36.0	.0	.0	.0	36.0
1904250417	20.0	.0	.0	.0	20.0
1904250418	24.0	.0	.0	.0	24.0
1904250419	28.0	4.5	.0	.0	32.5
1904250420	32.0	.0	.0	.0	32.0
1904250421	24.0	.0	.0	.0	24.0
1904250422	28.0	.0	.0	.0	28.0
1904250510	20.0	4.5	.0	.0	24.5
1904250511	36.0	.0	.0	.0	36.0
1904250515	32.0	.0	.0	2.0	32.0
1904250516	20.0	4.5	.0	.0	24.5
1904250517	16.0	4.5	.0	.0	20.5
1904250609	28.0	4.5	.0	.0	32.5
1904250610	36.0	.0	.0	.0	36.0
1904250611	20.0	4.5	.0	.0	24.5
1904250612	16.0	4.5	.0	.0	20.5
1904250613	32.0	.0	.0	.0	32.0
1904250708	20.0	.0	.0	.0	20.0
1904250709	24.0	4.5	.0	.0	28.5
1904250710	32.0	.0	.0	.0	32.0
1904250711	24.0	.0	.0	.0	24.0
1904250712	24.0	.0	.0	.0	24.0
1904250713	20.0	4.5	.0	2.0	24.5
1904250714	24.0	4.5	.0	.0	28.5
1904250808	20.0	.0	.0	.0	20.0
1904250809	24.0	.0	.0	.0	24.0
1904250810	28.0	.0	.0	.0	28.0
1904250811	24.0	.0	.0	.0	24.0
1904250812	20.0	4.5	.0	.0	24.5
1904250813	16.0	4.5	.0	.0	20.5
1904250814	28.0	.0	.0	.0	28.0
STAND AVERAGES	26.8	2.3	.2	.1	29.2

Now consider three timber harvest plans that are proposed for this stand type, as shown in Figure 3. Using the average volume figures for the stand, each harvest plan area will yield the same volume per acre, 29.2 MBF, and an estimate of the total harvest plan volume is a function of the plan acreage. An alternate approach is to relate the resource inventory plot data to the harvest plan areas. Average plan attributes are estimated by summarizing only those plots that were measured within each of the harvest plan units. Using this approach, the estimate of the total volume production is a function of the volume per acre specific to each harvest plan area and the harvest plan acreage. Data from plots that are outside the specified areas are not allowed to contribute to the development of information that describes each specific area. The harvest plan volumes determined using these two approaches are shown in Table 3.

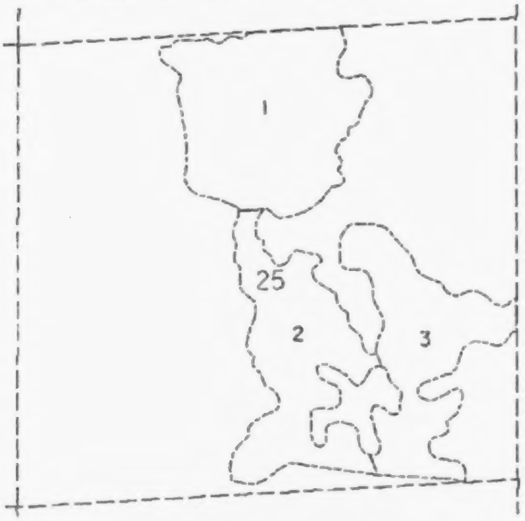

Figure 3. Timber Harvest Plans

In this example, the volumes of harvest units 1 and 2 are significantly different from the average stand volume of 29.2 Mbf per acre when tested at a 95% level of confidence. Which estimates are better to use, those based on the average stand volume or those based on the average of the plots that fall within the harvest plan areas?

This question can really only be answered following an analysis of the actual production of the harvest plans relative to the volume projections. However, as we lack this type of information because we are projecting harvest volumes, I would anticipate that the volumes based on the plots specific to the harvest plan areas are a more accurate estimate since these volumes are not based on plot data measured outside of the harvest plan area. With one possible exception, the harvest plan volumes estimated using resource inventory plot data will generally yield more reliable estimates of the anticipated harvest volume than the harvest plan estimates based on the generalized stand volume per acre data. This exception is that less accurate estimates may be generated when the number of inventory field plots is so low that the individual harvest plan attributes are based on an insufficient sample of the harvest plan area. The sample size and/or standard deviation of the inventory data may be monitored and when insufficient or highly variable inventory plot data exist within a particular area, the average stand attributes may be used in place of the specific harvest plan attributes.

Thematic Database Maintenance and Update

Many thematic databases, such as a vegetation database, represent dynamic information. The data are subject to change due to natural influences, such as wildfires, and human influences, such as timber harvesting. These changes have the potential to affect vegetation boundaries and attributes. Vegetation information is also subject to subtle changes as time passes, as regeneration, growth, and mortality of vegetation result in changes of vegetation characteristics. Resource inventory field data plays two significant roles in the update and maintenance of vegetation type data that enable more accurate updates of stand attributes and prevent degradation of the quality of thematic databases of this type.

One role of the inventory plot data involves the estimation of remnant or residual vegetation characteristics following a change of the boundaries of a type or stand. This change, which might be due to timber harvesting or a wildfire, is often represented in the vegetation database by updating the linework to reflect the affected stand boundaries, recalculating the acreage of the remnant stand types, and

Table 3: Projected Volume by Plan Area

Harvest Unit	Acres	Sample Size	- Volume per Acre - Stand	Plots	Percent Difference	Smean
1	86.1	19	29.2	26.1	-10.6%	1.10
2	63.0	17	29.2	32.3	+10.6%	1.40
3	59.3	16	29.2	29.5	+ 1.0%	1.61
Total	208.4	52	29.2	29.2	0.0%	0.85

Table 4: Diameter-Frequency and Volume Distribution

Elapsed time = 15.00 yrs
Report is totals by DBH class - All species combined

Stand label = 19043302

********* growing stock *********||———— growth ————||

Dbh	Trees /Acre	B.A /Acre	Cunits /Acre	Mbf /Acre	B.A.	Cunits	Mbf
4- 6	24.3	3.48	0.0	0.00	0.32	0.0	0.00
6- 8	28.9	7.98	1.3	0.00	1.26	1.3	0.00
8-10	38.5	16.17	3.6	1.26	3.49	1.3	0.83
10-12	25.5	16.68	4.7	1.86	3.52	1.3	0.64
12-14	21.0	19.68	5.9	2.54	4.42	1.8	0.91
14-16	16.6	20.35	6.7	3.09	4.53	2.0	1.10
16-18	14.4	22.83	8.0	3.96	4.93	2.2	1.30
18-20	12.7	24.84	8.7	4.50	5.46	2.4	1.49
20-22	6.1	14.80	5.4	2.98	3.11	1.4	0.91
22-24	2.4	7.41	3.1	1.84	1.30	0.7	0.47
24-26	2.4	8.13	3.4	2.02	1.43	0.8	0.54
26-28	2.7	10.59	4.2	2.55	1.97	1.0	0.70
28-30	3.2	14.26	5.6	3.53	2.50	1.2	0.90
30-32	2.5	13.00	5.2	3.32	1.83	0.9	0.67
32-34	2.0	11.79	4.7	3.03	1.61	0.8	0.62
34-36	1.5	10.06	3.9	2.57	1.36	0.7	0.54
36-38	1.1	7.66	3.0	2.00	0.82	0.4	0.33
38-40	1.0	8.22	3.1	2.13	0.86	0.4	0.35
40-42	0.7	6.09	2.3	1.56	0.64	0.3	0.27
42-44	0.2	1.64	0.6	0.44	0.11	0.1	0.05
44-46	0.2	1.81	0.6	0.45	0.18	0.1	0.08
46+	0.4	5.73	2.2	1.60	0.23	0.1	0.10
Totals	208.4	253.20	86.2	47.21	45.88	21.3	12.80

Average dbh = 14.93"
Average ft³/tree = 41.36
Average bf/tree = 226.54

transferring or copying the attributes of the previous stand to the remnant stands. Consider the timber harvest plan units in Figure 3 again. Assume that Unit 2 was completely harvested. What are the appropriate volumes to associate with the remnant stand types represented by Units 1 and 3 so that the quality of the data is maintained? If we update the boundaries, calculate the acreages of these two units, and transfer the previous stand volume of 29.2 Mbf per acre to each stand, we may be sacrificing some accuracy of the stand attribute data. This potential inaccuracy affects both the updated estimates of the forest inventory and the projections of potential harvest from the remnant stands. The alternative means of updating the remnant stand attributes would be to base the updated vegetation attributes on the summarization of the plots located within the remnant stand types. As has been demonstrated, this approach will generate estimates specific to the remnant stand areas and may yield estimates that are significantly different from the average volume of the previous stand. The attributes of remnant stand types may be more accurately described by including the resource inventory plot data in the process.

The second role of the resource inventory field data involves the use of forest growth and yield models that project changes in the stand attributes with the passage of time. It would be impossible to consider the use of resource inventory data in the manner proposed in this paper without possessing the capability to project or 'grow' the resource inventory field data to different points in time. Plot data is static and represents the resource at the time of its measurement. It would be impractical to remeasure inventory plots every year. The plot data must be updated or 'grown' to reflect vegetation characteristics at different times. There are two basic forms of growth and yield models. One type is based on stand characteristics, such as basal area, volume, and trees per acre. The other type is based on tree characteristics, such as species, dbh, height, and percent live crown. Resource inventory plots may be the basis of either stand-based or tree-based growth and yield estimates. Updated vegetation attributes based on a stand-based model may be developed using the **plot_detail** information for each of the plots in the vegetation type being updated. Updated vegetation attributes based on a tree-based model may be developed using the **tree_detail** information describing trees on the plots within the vegetation types being updated. The vegetation update information will be based on the average change as reflected by the individual plots rather than the change of the average stand or tree attributes of a vegetation type. This approach of averaging the growth of individual plot characteristics to develop growth and yield updates has been demonstrated to provide more accurate estimates than growing average stand or tree values. Growth and yield models are complex models that normally do not grow stands or trees so that the growth estimate of the average plot or tree list is equal to the average of the growth estimates of individual stand attributes or tree lists. Therefore, growth projection using individual plot data will contribute to the long-term maintenance of the quality of the thematic vegetation information.

The Development of Detailed Tree Specific Information

The integration of resource inventory plot data in a GIS also enables the development of more detailed estimates of vegetation characteristics than are available from generalized thematic information. The resource inventory data that is stored in the **tree_detail** table is the basis of very detailed estimates of stand information, such as diameter frequency, log size, and volume distributions (see Table 4 below). These types of detailed information play significant roles in the development of many forest management decisions and estimates, such as logging production rates, stumpage estimates, and harvest schedules. This information cannot be developed as well from generalized average stand characteristics. It is possible to store stand attributes such as the average dbh, log dib, or the percent of the total volume of each major species group. It is also possible to store a number of generalized diameter-frequency distributions that are keyed to age, site, species, and stocking. However, these vegetation parameters and distributions are not static and should be re-estimated as vegetation types continue to grow and develop. As our information needs increase, we find that we require current detailed information to be able to evaluate and discriminate between very similar, but still different choices. Otherwise, the models we utilize and the decisions we make may be insensitive to vegetation characteristics that exist on the ground but not in the database.

The advantage of integrating the resource inventory field data with the other GIS databases is that current and detailed site-specific estimates may be developed on an 'as needed' basis. Spatial analysis is used to identify and extract plot data from the database for specified areas. The plot data may then be 'grown' to a specified time or year, if necessary, and subsequently processed using programs and models that include tree volume and taper functions to develop current projections of stand tables, log distributions, and grade mixes.

Conclusion

For many years, resource management professionals have relied on inventory plot data to develop estimates of vegetation characteristics. There has been a tendency to develop generalized thematic type information from the resource inventory plot data and, more or less, abandon the subsequent use of the inventory plot data to develop up to date and more accurate information and resource descriptions. GIS capabilities that enable the performance of spatial analysis and the management of large databases have enabled the integration of resource inventory plot data with thematic type information. This data integration enables the estimation of resource attributes and characteristics that are more accurate, reliable, and detailed than generalized thematic type information. Resource managers are now capable of developing better information for use in the decision making process, which enables them to evaluate more alternatives, be aware of small but significant differences, and make better decisions.

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Integration of Spatial Analysis Technologies for Forestry Applications

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Abstract

Industry in conjunction with the forestry and natural resource disciplines are coming under increasing pressure to better manage the resources with which they work. It has been recognized that the ability to better understand and manage these resources can be improved through the use of GIS technology. The use of GIS in managing and analyzing geographic/spatial information makes that information even more valuable. It is integration that gives GIS this power. A GIS is able to bring varied forms of information from many different sources together and relate it through one common trait - spatial location. However, integration need not stop at the storage and management of varied types of spatial data. Perhaps one of the most powerful capabilities geographic information systems can offer the forestry and natural resource disciplines is the ability to integrate the many existing forms of spatial analysis and their resultant information more closely, providing an analysis environment capable of more accurately modelling the complex interactions of the world in which we live. The application of these spatial analysis techniques and the integration of these technologies provides the decision maker with planning tools and capabilities limited only by their imaginations.

This paper will present the benefits of spatial analysis techniques and their integration as they relate to the forestry and natural resources disciplines. The latest in spatial analysis techniques including object-oriented techniques, and the integration of these technologies will be discussed with examples of applications in hopes of spurring further creative thought on the integration of these technologies. It is hoped a glimpse of the future of GIS analysis in forestry and natural resources will emerge, where the benefits of the varied forms of analytical technology can be realized through integration, without compromising data integrity or the fundamentals of the various disciplines which these technologies address.

Introduction

> "Reason's last step is the recognition that there are an infinite number of things which are beyond it. It is merely feeble if it does not go as far as to realize that."
>
> Pascal, 'Pensées.'

Many methods are used in the collection of information about the world around us. This data, once collected, flows between departments and disciplines, waiting to become knowledge through analysis. In the past several years many advances in geographic information system (GIS) technology have increasingly made it evident that the only limitation to our ability to obtain this knowledge about the spatial information around us is our own understanding and imagination. The advances in GIS technology brought about by advances in the mapping, computer, and related sciences have provided us with tools capable of modeling the world in which we live and its complex dynamic interactions. While there are some limitations in our ability to analyze the environment around us, these are for the most part tied to the tools which we are using. These limitations are due to either the software's specific data structure or analytical capabilities. It is therefore necessary to clearly understand not only the benefits of certain spatial data structures and analysis tools, but also their limitations. It is also important that these data structures and analysis tools allow for the smooth flow of data between them. The integration of these tools and structures will then allow us to realize all their benefits, and better model our environment.

Graphic Data Models in Spatial Analysis

In GIS, we attempt to create a model of the environment. This modeling involves the abstraction of space as a number of elements or features (i.e., highways, rivers, mountains, etc.,). The location of these features must be defined in relation to some standard, thus coordinate projection systems are utilized to define 'where' these features are. There are two methods used to graphically represent/display GIS features: the grid/raster model, and the vector model. In the raster approach, the homogeneous units are cells, and in the vector approach, the homogeneous units are points, lines, and polygons (Aronoff, 1989).

Grid/Raster Data Model

Before the marriage of CAD systems with relational database systems, the common means for GIS analysis was the grid/raster data model. The vector model was traditionally utilized for mapping alone, and only in the relatively recent past has it been utilized to perform GIS analysis. The grid is commonly used to represent map features utilizing a nominal value associated with a specific row and column in a specific location to represent a feature or a geographic region. Grid rows and columns or X and Y values make up the spatial location of data, and attribute values are associated with these locations as integers or a Z value. This Z value can represent a number of different attributes. These attributes often consist simply of a value which represents spectral characteristics as is the case with satellite imagery, or an elevation as with digital terrain modeling. Resolution is defined as the distance between X and Y values, and is easily thought of as the smallest unit on the map. For example, one might have a soils map in grid/raster form which has a 1 meter square unit as the resolution, where the distance between grid lines is 1 meter.

Grid/raster data is often used in the area of digital terrain modeling, where a model of a terrain can be reproduced digitally. Satellite images are utilized to detect changes in the environment, such as urban expansion or deforestation, or in landuse classification. This sort of data is often utilized separately from vector data, save for occasional vector/raster displays. It is important to note that early GIS analysis utilized grid/raster data for many of the kinds of analysis which are more often done today using the vector model. Because of this, those forms of analysis which are best suited for the use of grid/raster data can be more clearly seen and understood. This then helps support the fact that the grid/raster model is in fact better suited to different kinds of analysis than the vector model. Grid/raster data is best suited for large geographic areas where the precision achieved through a vector model is less important than the ability to perform complex mathematical analysis of attribute data. Some grid analysis systems are able to provide a level of overlay analysis capability not currently available within the vector model. Complicated mathematical expressions can be applied to grid/raster values to derive new thematic data layers. Grid/raster data can be of any defined resolution, but it is less suited to representing precise boundaries, such as parcel lines, than is vector data. Grid/raster data is better suited to represent thematic data which has imprecise ('fuzzy') boundaries, such as soil types, lake shorelines or landuse classifications. The grid/raster data model has shortcomings. Depending upon the use of quadtree structures and compression techniques, it may require large amounts of disk space for storage. Additionally, the ability to relate grid/raster data to the power of relational database technology has only recently been pursued seriously.

Vector Data Model

Vector data involves the use of point, line and polygon geometry to define the shape and form of the features in a GIS. For many years this model was used simply to define the spatial extent of map features. Mapmaking throughout history, in fact, utilized the vector data model, first as line drawings and today as digitally-stored vector data. This model uses the concepts of plane geometry to represent map features and thus provides a precision which cannot be achieved through the grid/raster model. The vector data model can provide a more accurate representation of the precise man-made features in the environment, since it is not limited to a specific resolution, but rather defines the actual form of a feature. As a data storage structure, the vector model is highly efficient, and is unsurpassed in graphical editing and management capabilities. It has been used traditionally in computer-aided design because of these powerful qualities. The vector model, however, has its shortcomings. The vector model can require more processing power during certain forms of spatial analysis than the grid model. Also, the precise lines of planar geometry are ill-suited to represent certain thematic data. Finally, the capture of vector data can be much more labor intensive and time consuming than grid/raster data.

Both the vector model and the grid/raster model have advantages and disadvantages whose detailed technical comparison are beyond the scope of this paper. This brief comparison is only meant as an introduction and building block. Regardless of the graphic model feature, intelligence must be added to provide a useful structure for analysis. GIS users have felt they had to choose between data models for their particular analysis needs.

It is the ability to fully integrate all forms of geographic information analysis and graphic data models in one environment that has been lacking. This integration is possible, without compromising the integrity of the disciplines which are brought together, if careful thought is given to the methods.

Data Structures and Intelligence in Spatial Analysis

Spatial analysis and the methods of arriving at an answer can vary from department to department, from discipline to discipline, even from individual to individual. This is also true of the level of feature or object intelligence required for certain forms of spatial analysis. For example, the measurement of a distance is quite different from the measurement of population growth and densities. In the first case no intelligence other than the spatial coordinates, or grid cell resolution is required. While in the second case, attribute intelligence about the numbers of people living within areas, or cells is required. The level of intelligence required and the associated data structure used will impact both on the system's requirements and methods used. There are basically three types of intelligence in GIS: Geometric, Attribute/Characteristic, and Topological.

Geometric Intelligence

Geometric intelligence concerns the locational definition of the feature in the GIS, whether it be represented in a vector or grid model. For this definition to have meaning, it is usually tied down to some form of co-ordinate system. The geometry provides intelligence about the dimensional qualities of the feature, and coupled with a coordinate system, its 'real world' locational information is defined.

Because geometric intelligence concerns locational information, issues of accuracy become important. Geographic data may be stored at different levels of positional accuracy. In performing spatial analysis, many layers of data may be incorporated which are of varying accuracy. The overall accuracy of the results of an analysis can be no better than that of the most generalized layer included in that analytical process. Thus, data capture must always be performed with a concern for the required accuracy of the output from the analysis. This becomes more apparent in the attempt to integrate the results of analysis performed within the vector model with that of the grid/raster model. Since there are basic differences in the representation of data in these two models, the precision and accuracy of the results of analysis performed using one model will always be affected when integrated with data represented by the other. Understanding the effects of incorporating the results from one form of analysis into another is crucial for the smooth integration of analytical techniques.

Attribute/Characteristic Intelligence

The feature intelligence commonly referred to as 'attribution' includes all the thematic information which defines 'what' a map feature is. Attributes are often termed non-spatial in that they do not in themselves represent locational information. Attribute/Characteristic intelligence can include everything from defining that a map feature is a tree, to the spectral reflectivity of a raster as is found in satellite imagery, to detailed ownership records for a parcel. This is perhaps the most used portion of the GIS. There are many methods for storing the attribute information. These can be categorized into several classes: proprietary file structures, network database structures, heirarchical database structures, relational database structures, or object-oriented structures. Relational database technology has been commonly coupled with simple graphic data to provide feature intelligence. The ability to move a feature and its attribute intelligence from one form of analysis to another will depend on how well the analysis tools allow for the movement of the data between the storage structures.

Accuracy as an issue for attribute intelligence is more related to the 'correctness' of the data, as opposed to the issue of positional accuracy related to geometric intelligence. This is often addressed by GIS users through a concern with data standards and database security. The control of database access in a GIS becomes of great concern to project managers, who want to ensure that the project's attribute intelligence is accurate. As is the case in any form of geographic information, its accuracy is only as good as the source data, and the care taken in its collection.

Topological Intelligence

Topology is perhaps the most important form of intelligence required for spatial analysis. Topology is the mathematical method used to define spatial relationships, specifying how features are spatially connected to other features, providing contiguity, containment, and connectivity. In some instances attempts have be made to define 'true' GIS as requiring a topological data structure that is continually updated and maintained by the system. This is not so, as many commonly performed spatial analyses do not need topology. For example, most grid/raster analysis has very little topological intelligence (only that inherent to its addressing structure) yet it can be the best means of addressing the problem at hand. Nonetheless, topology provides data structures with one of the most powerful forms of intelligence for more accurately modelling the complex spatial relationships within the environment.

The maintenance and storage of topology can be a machine space intensive endeavor. This is because the potential set of relationships within a complex spatial database is enormous. Many times a system will be stretched to its processing and memory limits, computing and storing topology for all features. It is therefore important to understand what method of storing topology is best suited for the desired application, its capabilities, and its ability to interact with other analysis methods.

The methods for storing topology in a GIS can be broken into three forms: topology in a file, topology in a set of relational database tables, and topology that is inherent to the object, as in some object-oriented structures. Topology can also be static or automatic; where static topology represents a snapshot in time, and automatic topology is topology which is inherent to the object and updated automatically. For updates to occur to static topology, it must be rebuilt either in its entirety, selectively in the area, or on the feature affected. Understanding that the maintenance of static topology is heavily machine and labor intensive, it is desirable that the topology be selective, thus requiring only the resources needed for the particular analysis to be performed. This can also streamline the processing and thus reduce the time required for the analysis, while at the same time allow for easier integration. Particularly in the implementation of large projects, it is often the case that a required universal implementation of topology is prohibitively large and cumbersome. Yet, machine limitations are quickly becoming less of a concern, as processor speeds, I/O speed, and memory costs decrease. Nonetheless, it is still a major concern to project managers to choose the most efficient methods to perform the analyses they require. Understanding how the topology is stored and maintained is important, since this will have an impact on the system's performance and capabilities for spatial analysis.

It is important to note that storing topology in a set of relational database tables can be more machine resource intensive than in a single topologically-structured file. It can increase the system's memory requirements as much as 13 times in some implementations (Stutheit, 1990). Relational databases can also present problems inherent in the manifestation of a feature and its characteristics from the database.

Topological Intelligence in Object-Oriented Structures

Object-oriented techniques are perhaps the best methods for storing topology for spatial analysis, as they are most able to accurately represent the dynamic spatial relationships in the world around us. The word 'object' though, is beginning to be used everywhere, for everything. In many cases, features are being called objects so a system may be thought of as object-oriented. In other instances, systems are calling themselves 'object-based' when they are actually feature-based with the features and topology being defined in tables in a relational database. True object-oriented systems allow for encapsulation and inheritance within the object. The power of these capabilities has yet to be fully utilized by the GIS community.

Object-oriented programming is a technique that encapsulates both data and procedures within an object. Not only does the feature as an object know its geometry and attributes, but also its topology. As an object, the feature knows what and where it is, what its relationships with other objects are, and how it would react in response to a certain action. True object-oriented systems support inheritance in the context of class hierarchies, enabling programmers to describe descendent objects efficiently by describing only the differences between the parent and child objects.

Typically, GIS users want to access and manipulate objects, not tables. To manifest an object from its corresponding tables an RDBMS must do relational joins, which is one of the slowest things they do. The model supported by an object-oriented system is more powerful in its capability to explicitly express the complex spatial relationships of objects in a GIS. The relational model has no notion of inheritance or aggregations, common characteristics of geographic features (i.e., drainage basin structures). Even if a table could be used to model a class, there is no way to explicitly express the notion of subclass (Loomis, 1990). Thus, with an object- oriented system, the whole concept of a separate database environment vanishes, as the object space becomes the environment. The relational model is mature and does offer many strengths over the object-oriented model when pure data management is the primary objective (Date, 1990). The best possible solution would be the use of true object-oriented structures where appropriate, and relational structures where they are appropriate, while also taking into account existing database structures which may already be present on existing systems.

It is important to remember that an object-oriented structure's strength is its ability to accurately represent the complex, dynamic relationships in the world around us. Because of this, the structure allows for dynamic analysis - interactive analysis provided by interactive, automatic topology. Within the object-oriented environment, topology is automatically updated. When an object is moved, every other feature affected knows it has moved, there is no rebuilding; it is automatic. When an action occurs (i.e., the river reaches flood stage) a feature reacts (i.e., dams open floodgates). 'What if?' scenarios are instantaneous.

Intelligent Data Structures

As more intelligence is added to the data structures, they allow for the ability to give features more meaning. This is only useful to the extent that the intelligence can be maintained as the features are moved and processed through different forms of analysis.

Forms of Spatial Analysis

Spatial analysis can concern the analysis of a feature or set of features' attributes, relationships, or temporal characteristics across a geographic area or space.

Attribute

The analysis of the attributes or characteristics of features is perhaps the most common form of analysis performed. This can include dimensional characteristics (length, area, perimeter, distance, etc.,) frequency/quantitative characteristics, statistical characteristics, or qualitative characteristics. To perform these types of analysis there is not necessarily a need for the definition of topological relationships; in many cases only geometric and attribute intelligence is required. Many of the analytical questions GIS users ask can be answered through the analysis of feature characteristics alone.

This is an area of GIS where grid/raster analysis can be very useful in many ways, including many of the traditional analyses we think of in GIS: land use planning, suitability studies, forestry, and environmental protection, to name a few. Complicated mathematical expressions can be applied to image and grid data, since this data consists solely of the attribute intelligence in the form of integer values associated with grid row/column pairs. Many layers of such data can be incorporated in highly complex overlay analysis processes, allowing users to perform suitability analysis based on a wealth of criteria, and do so more efficiently than a similar overlay using topological structures. Large geographic areas and vast quantities of spatial data can be analyzed allowing for efficient analysis.

Attribute analysis can consist of many vector model related queries which do not require topology. The power of relational databases can be utilized, and can be coupled with the graphic map features without having any topological relationships established. The GIS functions which fall into this category are sometimes forgotten, but are nonetheless at least as important as topology for many users. These include queries which involve single themes, such as "show me all the ownership information about parcel 1-A," in which a relational database record which corresponds to a graphic feature can be found. It is typical that such single theme queries are performed through an association between graphic map features and relational database records. Queries of the relational database itself can be handled through a graphic interface, and thus corresponding graphics can be displayed easily.

Topology does not exist in the grid/raster model, and does not need to exist where basic query capabilities are the norm in the vector model. Topology is needed, however, to provide for higher analytical functions relating to the spatial relationships of features to each other, within individual layers of data, as well as across many themes.

Relationship

The analysis of the spatial relationship of features in most cases requires some form of topologically intelligent data structure. Although there are certain spatial analyses possible without topology, such as neighborhood analysis functions within the grid/raster data model, it is the primary tool for relating map features to one another spatially. There are many spatial relationships which are easily represented only when a topological structure of some sort is implemented. Proximity, adjacency, coincidence, contiguity, and intersection, among others, are the kinds of relationships which topology allows us to model. Since topology involves the modeling of relationships between point, line and polygon features, it is most useful for the user to be able to define spatial operators based on the the plane geometry which defines real world features. Spatial operators such as 'areas which fall within other areas' or 'lines which intersect lines' can identify, for example, lakes within forest areas or intersecting roadways. The driving force behind the growth of GIS toward the vector model has been its ability to precisely delineate ground events through the use of plane geometry, and associate attribute information with them as well as to each other spatially. The advancement of relational database technology has allowed for the integration of database information as feature attribution. The advancement of topological structures has allowed these intelligent features to also have knowledge of their surroundings.

There are many ways that topology can be called upon to perform analysis. Many examples can be illustrated, and they are limited only by the spatial relationships which can be established; for example, "What parcels lie adjacent to Highway 20 and intersect with tax district 12?" or "Which areas of high quality forest timber fall within a 10 km buffer from access roads?". The questions are numerous and various. In addition to polygon overlay analysis, there are other applications of the analysis of spatial relationships, such as network connectivity analyses.

Temporal

Topological relationships provide answers to many analytical questions, but they cannot provide an easy means of performing temporal analysis. The analysis of temporal characteristics of geographic features and regions is commonly applied in the environmental sciences and for maintenance requirements in utility and infrastructure management organizations. This can include change detection or event monitoring. This type of analysis is usually limited to the use of image processing technology. Imaging systems are designed to read in raw raster data and provide tools for classifying that data, and significantly, to analyze the temporal changes. Typically, users can read raw satellite imagery or other imagery into their system, and perform such analyses through automated functions. A satellite image of a forest area can, for example, be compared to older imagery in the system to find areas of deforestation, reforestation, species succession or other qualitative changes in the area. Imaging systems are useful for this and other analyses, but are rarely integrated with other analytical products.

Integration of Spatial Analysis

A methodology for the integration of spatial analysis technologies must first begin with an understanding of the individual disciplines themselves. The various disciplines which perform different types of GIS analysis can be integrated, but must first be understood in their own right. Likewise, GIS projects should be well-defined before any computer system or software technology is implemented. The project manager should clearly understand the goals for his project, and the type of results which are needed. It is important to know what answers are being looked for, and what are the best methods to find them. Often there are sacrifices made because the user's system is incapable of supplying the functionality needed. Similarly, it is often the case that the types of functions needed and systems which supply those functions are so unrelated as to make it difficult to integrate them smoothly. It is important to understand that there are many benefits in the ability to carry results from one type of analysis to another totally different form of analysis. These benefits can only be realized when consideration is given to the ability to move data easily and cleanly between applications. It is therefore important that a methodology for the integration of spatial analysis allow for the appropriate data structures and tools which allow the movement of data to and from the application best suited for finding the answers that are needed.

For example, suppose there is a need to find areas of high forest densities that correspond to land areas designated as unprotected (or acceptable for harvesting). The classification of forest density can be performed using image processing tools. To this end, raw satellite imagery can be read and classified. That classification, however, might be found inaccurate when other factors are considered, as when an image 'footprint' could be classified as high density based on image processing techniques, yet could be incorrect when slope information is taken into account. This means there is a need to incorporate slope information to determine a more accurate assessment of the forest area in question. Digital terrain modeling products are designed, among other functions, to take elevations and output slope polygons to a vector model. The problem then becomes how to overlay the classified image with the interpolated slopes. A means for performing this task is to translate the slope polygons into a grid/raster format, and then construct an analytical overlay to account for the effect of slope on the image classification. In addition, the extent of unprotected or harvest-ready areas might be stored in a land records system which utilizes a vector model. This means the results of the forest density analysis needs to be incorporated into the topology of the land records system in order to find and report on forest areas deemed acceptable for harvest and having high density. What this example requires is a system which can integrate digital terrain modeling with image processing and topological, vector-based analyses. There are additional analytical tools which could be incorporated as well. The forest areas to be harvested might be relatively inaccessible, and thus an analysis of travel routes on existing roads and optimal paths for new timber roads should be performed. These additional needs would require a linear network analysis tool for optimal path routing on existing road networks, and the ability to determine optimal paths based on road building costs to the harvest areas.

This scenario is utilized to illustrate a cogent point: that a GIS must allow its users to have access to all the tools needed to complete the project. A patchwork of tools is inefficient, and may not allow for the realization of the goals that were set for the project. What is needed is a means to integrate all these tools in a common environment. This capability will allow not only various kinds of spatial analyses, but visualization and simulation capabilities. In some cases, a single form of spatial analysis is all that is required to understand a complex event which is occurring or has occurred. In other cases, many forms of spatial analyses may be required. There are many benefits and forms of new knowledge which can be gained through the integration of spatial analysis technologies. For this to occur, a clear understanding of the application of these technologies and well planned objectives are required. Once these are in place, an environment which allows this integration must be present.

Conclusions

Integration is an exciting and irreversible trend that is revolutionizing the way we interact with, use, and extend our computing environment (Parsaye, 1990). As the power and complexity of our tools increase, there will be a growing gap between the level of theoretical development in many areas of spatial analysis and the corresponding levels of operational competence and practical application. It is imperative that GIS tools be able to integrate data, regardless of it's source or structure. The methodology for the integration of spatial analysis requires an understanding of the desired goals, and a single work environment that provides the tools to move the data between applications and systems, through workflows, and across disciplines.

Acknowledgements

This material has been adapted with permission from a previous similar work presented at GIS/LIS'90 entitled "A Methodology for the Integration of Spatial Analysis Technologies", vol. 2, **GIS/LIS'90 Proceedings**, Copyright ASPRS, ACSM, AAG, URISA, AM/FM International, 1990.

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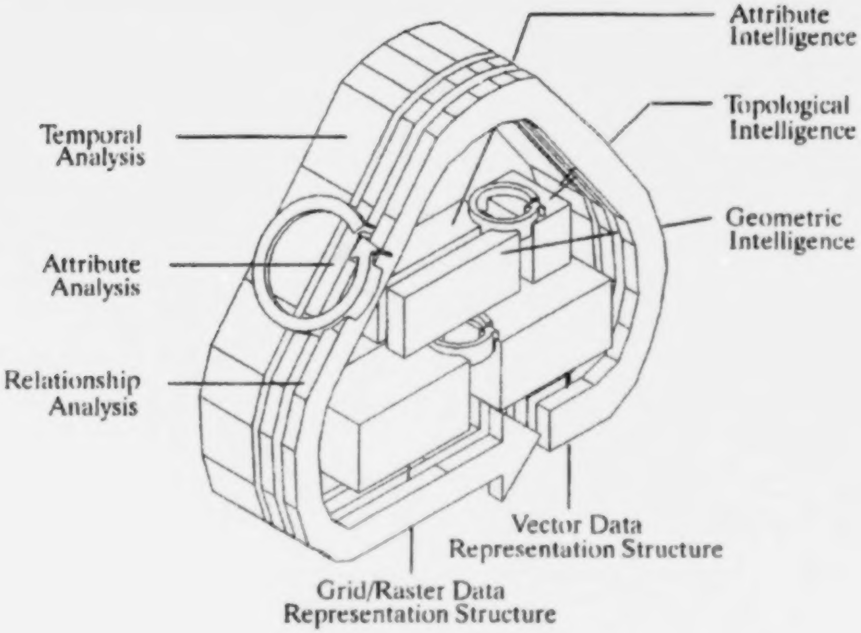
Attribute Intelligence
Topological Intelligence
Geometric Intelligence
Temporal Analysis
Attribute Analysis
Relationship Analysis
Vector Data Representation Structure
Grid/Raster Data Representation Structure

Figure 1. Integration of GIS Intelligence, Representation Structures and Analyses

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Concurrent Session 3

B.C. Ministry of Crown Lands - New Initiatives

General Framework for Geomatics Data Exchange

The Digital Atlas of British Columbia

Requirements of a Canadian Geomatics Interchange Standard

Setting the Stage for Data Sharing in British Columbia

GIS'91

Symposium

Vancouver
British
Columbia
February 1991

General Framework for Geomatics Data Exchange

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Abstract

The ability to share geomatics data has become an issue of provincial, national and international importance. Around the world, there have been a number of efforts aimed at developing data-transfer specifications suitable for many different kinds of spatial and non-spatial data. Fundamentally, all such specification efforts are highly technical in nature, as they must be to provide the mechanics of data transfer. Nevertheless, transfer does not occur in a vacuum. There are organizational and user concerns which must be recognized, including how data is accessed, how updates and queries are made, who needs to know what about the specification, and what tools are available to help different types of users. The technical environment in which the transfer will take place may also have a bearing on the specification and its use. These various issues taken together define a general framework for geomatics data exchange.

Introduction

Recent developments in Canada, Great Britain, the United States, the NATO-aligned countries and elsewhere have centred on specifications for the transfer of various kinds of geomatics data. Within British Columbia, a similar effort has taken place, leading to the creation of the Spatial Archive and Interchange Format (SAIF, pronounced 'safe') (Geomatics Unit, 1990; Geomatics Unit, 1991). SAIF and many of these other interchange specifications are currently undergoing evaluation by working groups of the National Committee on Geomatics, established by the Canadian General Standards Board (Latour and Sondheim, 1991). Regardless of the results of the evaluation, any specification must be seen in a context broader than the data transfer mechanics alone. This paper describes the larger framework as it may pertain to the potential use of SAIF.

Organizational Perspective

To handle economic and environmental concerns effectively, society must be able to act and react in a timely manner. Planning, assessment and development decisions are constantly required. Ideally, such decisions take into account all relevant information. Planners, managers, developers and other users would like to assume that all relevant data is readily available to them with a minimum of complications. From their perspective, peer to peer connectivity will help them meet their information needs (Menes and Sondheim, 1990). An individual can get pertinent data from anyone else who may be maintaining that data, as appropriate.

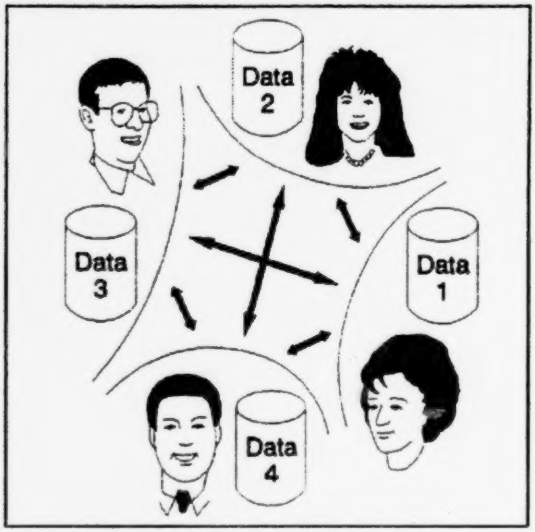

Figure 1. Peer to Peer Connectivity

Unfortunately, even when the information exists, it is often difficult to find and use. Major problems frequently result from different organizations applying different managerial and technical strategies to the underlying data. That is, problems with transferring and exploiting the data may exist for reasons related to policy, database management and communications methods, incompatibilities in data structures and other causes. If transfer is to be practical in an operational context, the larger framework for handling data transfer must recognize a series of layers of organizational interaction. Seven layers can be depicted as follows:

1. Central to each organization is its data. Of importance for the purposes of this document is any geomatics data held by the organizations.
2. One or more data models describe the data of each organization. Preferably, for all geomatics data, a single data model will apply to all dbms, communications, and system functions. Where this is not the case, mappings must exist between the different models if transfer is to be successful.
3. The database management system(s) house(s) the data, with the conceptual schema of the data provided by the data model. The dbms also provides query and update capabilities, including query anwupdate creation, query processing, and transfer of the results using the communications provided.
4. Access to the dbms resident data is through various kinds of communications. These include anything from floppy disks to broadband ISDN. The dbms should be able to make use of different kinds of transfer methods.
5. Functions such as ordering, distribution, tailor-made GIS operations, data viewing capabilities, etc., are included in the applications layer. To the user, much of the value comes from this layer.
6. The variety of functions and data available to the user demand that a comprehensive management strategy be enacted. Such management ensures viability as a business activity.
7. Because of the far-reaching implications of the structure, high-level policies must be promulgated throughout the organizations, including policies related to transfer.

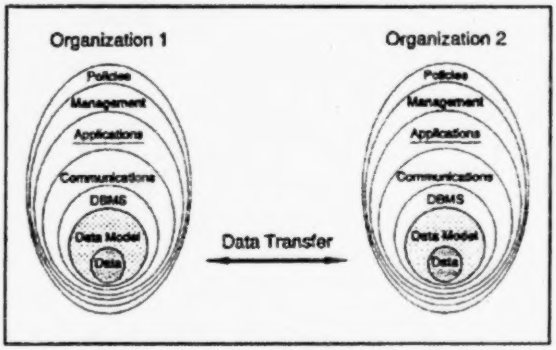

Figure 2.Data Transfer Between Organizations

In practice, these layers are not independent of one another. Policies are likely to have an impact at all levels. The existence or characteristics of various types of data may make some procedures and policies meaningful but not others. What is clear from this analysis is that in reality the details of a data format are part of a larger process of information exchange.

The peer to peer connectivity of Figure 1 can be extended to encompass data exchange among agencies, companies, and countries. Implicit in Figure 3 is the recognition of the overall transfer process.

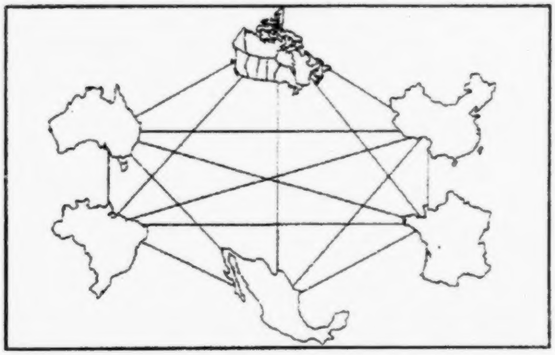

Figure 3. Worldwide Connectivity

The Spatial Archive and Interchange Format (Friesen andSondheim, 1989; Sondheim, et al., 1990) has been developed to directly address technical transfer format requirements, but to do so in a way which facilitates general update, query, and geographic information system (GIS) operations.

User Perspective

As with many technical concerns, SAIF and its associated operations should be hidden entirely from the typical user involved in geoprocessing applications. SAIF can be considered as a black box aiding data transfer, if its existence is even known. A well designed application will access the geomatics data as required; from the perspective of the user the data's location or particular format are of no real interest. Questions about data security and integrity, about data transfer, and about appropriate protocols are handled transparently by the software, as suggested in the following diagram.

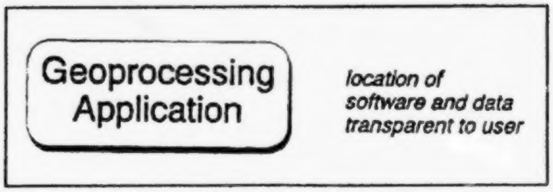
Geoprocessing Application
location of software and data transparent to user

Figure 4. Ideal User's Perspective

A user with a less polished application environment, or with an ad hoc procedure to perform, may need to recognize where he or she is on a computer network and where the data of interest is resident. In this case, the ability of desktop and data storage equipment to inter-operate is provided, but the transparency of the process is lost. The user explicitly sends a request for data and subsequently receives it. Similarly, he or she may create an update and then transfer it to the database. As shown in Figure 5, the use of telecommunications is assumed. It is also possible that the request may be made by telephone, fax, or letter, and that data transfer from or to the database will be handled by tape or disk.

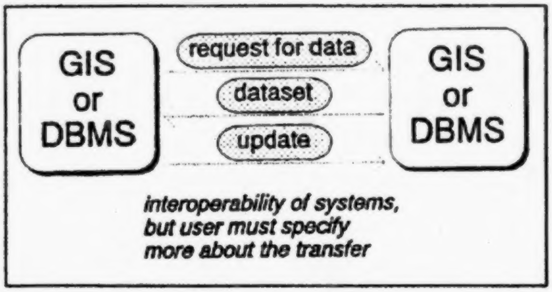
GIS or DBMS
request for data
dataset
update
GIS or DBMS
interoperability of systems, but user must specify more about the transfer

Figure 5. Alternative User's Perspective

To emphasise how SAIF should look to the typical user, consider the extension of the graphical user interface to the geographical user interface (GUI). Figures 6 and 7 show a mock-up of an application using windows and pull-down menus. Included within the application are functions to Update, Query, Browse, and View.

Updating may involve creating the update, that is, defining the data to be used as additions or corrections to the existing data. Once an update has been defined, the user may wish to review it and modify it, and he or she may wish to run the data through validation procedures. Such procedures check the data to ensure that it follows certain rules, such as using only recognized feature classes or testing to see whether polygon closure is met. Once the user is satisfied with the data, it may be sent to the database. SAIF does not have any facility to create updates, but data transferred as a result of an update may be moved using a SAIF format. As well, the structure of SAIF facilitates the development of validation routines.

A potentially complicated problem with updates concerns time and moving objects, such as sewage effluent flow, vehicular or animal movement, aircraft or spacecraft movement, etc.. Monitoring activities may involve tracking location over time. The user may wish to add the new position/time information to the data for an existing object; he or she should not be forced to create multiple versions of the same object. Here again, the design of the SAIF data model makes this easy to do.

A user may not be interested in updating the database, but instead may require answers to certain questions. These answers would generally be subsets of the database which meet certain query conditions or summary statistics. A query must first be created, or an existing query may be modified. The query may include specific geographic position or time criteria (e.g., location) based on coordinates, mapsheet or watershed names, zooming in from a small scale map of the province or country, etc.. Additionally or alternatively, specific objects or types of features (e.g., mineral deposits or roads) may be of interest. Finally, the query must be sent. If a batch mode has been specified, the results may have to be requested explicitly. Query functions are outside of the scope of SAIF; however, SAIF has been designed to ensure that all such queries can work efficiently with geomatics data transfer requests.

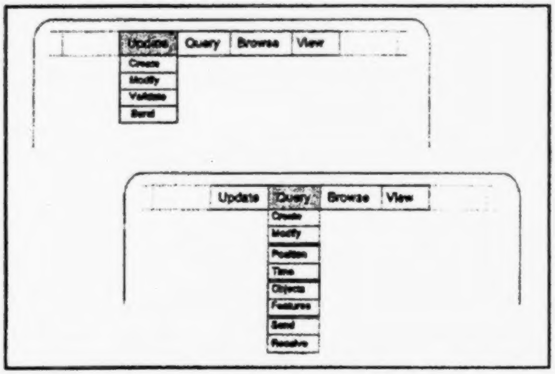

Figure 6. GUI for Updates and Queries

A user may wish to browse or inspect the specific data values of particular geographic objects, provided that the data may be examined in a form which is readily understood. In this case, he or she may identify the objects through pinpointing their geographic or temporal locations or by specifying the particular object names, as with the query function. Of interest may be all the data about the objects, or only certain kinds of data based on their feature identification, attribute descriptions, or geometric characteristics. Associated with SAIF is a SAIFbrowser utility, which provides the user with many of these capabilities.

Simple, graphical views of the data may also be available. Here as well, the user may specify location in several different ways or may define specific objects or types of features. A particular projection, such as UTM or polyconic may be of interest. In addition to zoom and pan options, the user may examine the legend and potentially change colours and line patterns. SAIFview is another utility designed to provide a number of these options.

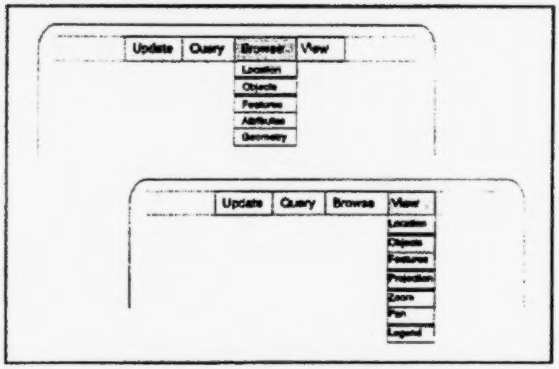

Figure 7. GUI for Browser and Viewer

The windowing examples above may, of course, be altered in many different ways, with different window and menu options, daughter menus, etc.. It is suggested that at least within an organization, ways of working with geographic data be standardized, beginning with the user interface. SAIF should be transparent to the user, though as a transfer format it should be an integral part of the user's technical environment.

Who needs to know what about SAIF

The previous section addressed the perspective of the typical user. In fact, SAIF will be viewed and used differently by different classes of users. Each type of user will be interested in different aspects of SAIF. Classified below are both SAIF users and areas of knowledge about SAIF.

Seven categories of users are recognized.

DA Database Administrator: the person responsible for managing the resources in a database environment. The resources are the database itself as well as the Database Management System and related software.

SD Systems Developer: an individual who develops new, or maintains existing, applications and integrates them into operational systems. Computer science personnel working for GIS vendors on translators fall into this category.

SE Specification Expert: a person with a strong technical background who understands the detailed underpinnings of the geomatics specifications used by his or her organization. These specifications may be either proprietary or non-proprietary in nature.

GD GIS Application Developer: a GIS expert who develops applications, partially or completely, by tailoring commercial GIS systems, often by using a high-level macro language available within the GIS.

AS Application Specialist: a person who has a thorough knowledge of the application from the perspective of the business or discipline, but who is not necessarily a computer systems expert, but is fully aware of GIS capabilities. The application specialist may also be responsible for contracts associated with data collection for example.

AO Advanced Operators: a person who carries out specialized functions and ad hoc operations with a GIS, typically at the request of an application specialist.

TU Typical User: a person who runs applications in which the geoprocessing component has been streamlined or embedded. Such users include professionals with interest in only a limited range of GIS capabilities, clerical support staff running repetitive tasks, and the general public at an information desk or signed on to an information utility, accessing certain types of data.

Twelve general categories of knowledge about SAIF can also be defined:

- Archive Implementation: the detailed encapsulation and encoding procedures used to store geomatics data. These may include software and specific formats.
- Transfer Implementations: the detailed encapsulation and encoding procedures used to transfer geomatics data, including relevant software and specific formats.
- SAIFtalk: the formal language used to define all SAIF data classes, including their structure, relationships, and rules. SAIFtalk is a high-level computer language designed exclusively for geomatics specifications.
- SAIF Data Model: the SAIF data classes, as defined formally or informally by text and diagrams. The model includes ways of specifying any geographically referenced object in terms of its geometry, attribute descriptions, and feature type.

- SAIF Metadata: data about data. SAIF metadata includes ownership, security, compilation method, coordinate system, and other high-level descriptions of the data. The metadata is part of the overall data model.
- User Syntax Notation: a notation or format for viewing any SAIF data. USN is designed for user comprehension as opposed to machine efficiency. Its purpose is equivalent to the use of tables to display data in a traditional relational context.
- SAIF Profiles: the means of indicating by an arbitrary code what kinds of SAIF classes are being used. For example, Profile 2 may mean that the geometry is represented by vectors without any topology. A profile is a functional standard used because of reasons of either policy or application effectiveness.
- SAIFfeature: a utility designed to aid management of the feature identification submodel used in SAIF, including feature definitions and their associated names and codes.
- SAIFview: a utility allowing users to view the data graphically on popular micro-computers and workstations. No knowledge of SAIF is required to use SAIFView.
- SAIFbrowser: a utility which lets the user look directly at the data values. Knowledge of the SAIF data model is expected.
- Communication Protocols: formal descriptions of message formats and the set of rules and conventions that govern the exchange of data among communicating stations (Data General, 1990).
- Database Management System: a system for managing and providing access to data. A dbms generally includes an update capability and the ability to create and process queries.

The user relationship to SAIF is clarified by the Chart 1, below ,which arrays the user categories against the areas of knowledge. Note that the most frequent user of geomatics data, the Typical User, is not expected to know anything about SAIF, but will nevertheless be able to view data graphically in a SAIF format. The Application Operator and the Application Specialist must understand some of the basic ideas in SAIF, but can avoid the more complicated aspects.

User Categories	DA	SD	SE	GD	AS	AO	TU
Archive Implementation	x		x				
Transfer Implementations	x	x	x	x			
SAIFtalk		x	x				
SAIF Data Model	x	x	x	x	x	x	
SAIF Metadata	x	x	x	x	x	x	
User Syntax Notation	x	x	x	x	x		
SAIF Profiles	x	x	x	x	x		
SAIFfeature	x		x	x			
SIUAFview	x	x	x	x	x	x	x
SAIFbrowser	x	x	x	x	x		
Communication Protoclos	x	x	x				
Database Managemen System	x	x		x			

The user categories are broad generalizations of the jobs found in many organizations. Many people will straddle two or more categories. The fact remains, however, that the majority of people who will be affected by SAIF need know little or anything about it. For those who need to konw the details, SAIF provides a rich set of stages or mechanisms of varying degrees of complexity.

Technical Environment

The SAIF data model has been designed to allow for a very high degree of flexibility in terms of actual use. It is recognized, for example, that magnetic tapes and disks are currently being used today, and for many applicaitons will continue to be used for some time to come. On the other hand, for small data volumes or where very high speed networks are available, telecommunicaiotns will increasingly be practical, whether based on copper wire, optical fibre, or microwave transmision. The exchage specificaiton should be effective for all these cases. That is, a single geomatics data model should be appropriate regardless of the media used for exchange.

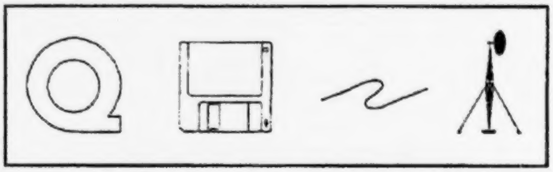

Figure 8. Different Communications Media

An extension of the idea of media independence is protocol independence. The term protocol can be considered in two contexts. The first is the formal expression of the data model or the data itself. For example, the current release of SAIF makes use of the User Syntax Notation to represent the data in a way directly readable by the user. Alternatively, an extended version of the Structured Query Language may be used for similar purposes. When such and exended SQL becomes an international standard, it will be possible to migrate smoothly from the current User Syntax Notation to this version of SQL. Such a migration will not cause changes to the data model. The current SQL standard can be used to express SAIF data, although it is somewhat cumbersome for that purpose. That is why the User Syntax Notation was developed.

The second notion of protocol independence concerns the message formats and rules assocoated with communicaitons. SAIF data could be sent as an electronic mail message (CCITT X.400) protocol. It could also be exchanged as a file using the File Transfer Access and Management standare (ISO 8571); a file or transcation using the telecommunications-oriented Abstract Syntax Notation (ASN.1, ISO 8824/8825) directly; a file encoded with the ISO 8211 implementation rules; or a file or transaction defined in an application-specific or proprietary database format. Thus, the same media (water, in the diagram below) may carry geomatics data following different communicaitons protocols (signified by the two boats).

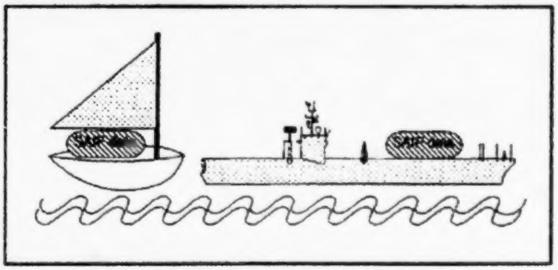

Figure 9. Same Media, Different Protocols

Many users will need to transfer geomatics data across existing or planned networks. This typically implies some sort of distributed processing environment in which work is divided between activities initiated by the user and thos performed elsewhere on the neetwork as a response. Networks may include one or more servers, whish are stations designed to perform specialized functions such as communicaitons, file stroage, format translation, or applicaiton analysis. Different kinds of workstations may be attached to the network, including personal computers, X-window terminals, and high-powered workstations. The network of a given user may be linked through a gateway or relay to another network, whether physically nearby or distant (Judge, 1988). In the context of geomatics data exchange, servers may house differnet databases and/or perform different functions. SAIF interchange and archive formats may be used to transfer geomatics data across the network or to store the data on a file server.

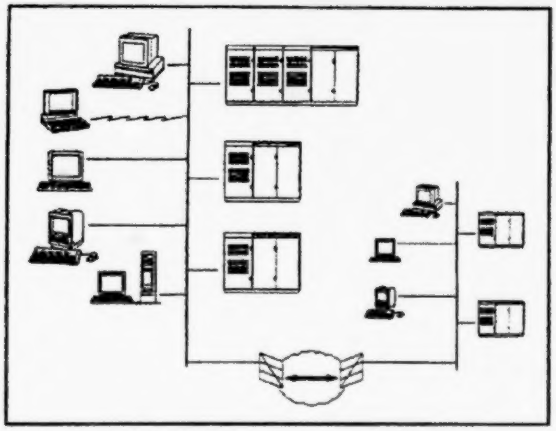

Figure 10. Interconnected Heterogeneous Networks

Regardless of the technical environment, SAIF is one of the building blocks in a larger framework, allowing a broad range of users access to a broad range of geomatics data.

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The Digital Atlas of British Columbia

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Abstract

The Digital Atlas of British Columbia (BC Atlas) is a concept derived from the cartographic practice of bringing together all of the available geo-referenced information for a region in a series of maps, related through the region boundaries. The current concept of the Atlas has evolved from the maps themselves to the underlying data and the systems which must be used to access and display that data. The BC Atlas is more than just a collection of data: it is a complete system, existing on a computer, which includes data, hardware; the computer and communications links, and software, the computer programs to access, search and display the data.

The BC Atlas, currently under development, is an outgrowth of the specifications for land related data and systems for the Province of British Columbia. Data will be provided at three scales (1:2 000 000, 1:250 000, 1:20 000) and will be stored in the BC-SAIF format, which is accessible to many systems.. Conceptually, the BC Atlas will be a distributed system which will eventually be incorporated into the Land Information Infrastructure. The data will be accessed via a geographic information system. Each aspect of the design of the Atlas utilizes the standards which will be in place for the Province. Management of the data reflects the principles defined by CLISP, the Corporate Land Information Strategic Plan.

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Requirements of a Canadian Geomatics Interchange Standard

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Abstract

In 1989, the Canadian General Standards Board established the National Committee on Geomatics with the intent of reaching national agreement on an exchange standard for geomatics data. The Committee created several working groups with broad participation from the provincial and federal governments, as well as from academia and the private sector. Through a series of meetings, the working groups reached over 100 points of consensus concerning the requirements for a geomatics data transfer standard. These requirements were further refined into 65 evaluation criteria, falling into a dozen categories. These criteria will be used to assess seven existing standards, with the aim of choosing one for possible national acceptance. Introduction

Introduction

Geographic information systems and related technologies are becoming increasingly common, not only for specialized analysis but also for day to day administrative tasks. In many cases, they would be much more effective if it were possible to integrate geographic data easily from diverse sources. For example, decisions regarding the construction of a new dam or the rezoning of a parcel of land may require information about the legal boundaries, the environmental conditions, and the topographic surface. The appropriate data may already have been collected, but may be stored in many locations on different databases and GIS systems. Getting all of the data to the place where the decision-making tools can utilize it in a timely fashion is practical for operational work only if a common exchange standard is employed. To date, there does not exist in Canada any nationally accepted standard for geomatics data exchange.

Recognizing the importance of the problem, the federal Interagency Committee on Geomatics requested that the Canadian General Standards Board create a National Committee on Geomatics for the express purpose of developing a national exchange standard or accepting an existing standard. The National Committee on Geomatics was established in June, 1989. The Committee in turn set up

Working Groups 1 through 4, charged respectively with Data Encapsulation and Encoding, Data Modelling, Feature Identification, and Data Directory and Cataloguing. The efforts of the first three groups are particularly germane to the specification and implementation of an exchange standard.

Data encapsulation and encoding are implementation issues involving detailed formats at the bit and byte level. Data modelling involves the specification of a set of concepts used to describe objects and their related data. The way a polygon is described is a data modelling affair; the use of a particular scheme to represent each number in the computer and the position of the bytes in a record are lower level encapsulation and encoding concerns. Consequently, the mandates of Working Groups 1 and 2 are complementary. The data model must encompass both spatial and non-spatial aspects of geographic data. One component of non-spatial data is feature identification, which amounts to a simple, standardized classification of geographic objects or entities into feature classes. Thus feature identification is recognized as a submodel of the overall geomatics data model.

A series of meetings beginning in the summer of 1989 and ending in late 1990 resulted in over 100 points of consensus, which were used to define a number of evaluation criteria. A report detailing these criteria is near completion. In that report, each criterion is explained at length with examples and diagrams, as well as an importance weighting. For the sake of brevity, this paper provides only a listing of the 65 criteria; they should be considered as preliminary only. Interested readers may obtain the complete report from the first author, who is Technical Secretary of the National Committee on Geomatics. The second author chairs Working Group 2. By the end of March, 1991, a second report should be available outlining the results of evaluations of seven candidate geomatics standards: CCOGIF (Canadian Council on Geomatics Interchange Format), DIGEST (Digital Geographic Information Exchange Standards), DX-90 (Digital Exchange, 1990), MACDIF (Map and Chart Data Interchange Format), MDIF (Map Data Interchange Format), SAIF (British Columbia Spatial Archive and Interchanged Format), and SDTS (Spatial Data Transfer Standard).

The remainder of the paper lists the evaluation criteria.

Data Encapsulation and Encoding

WG1-1 The data encapsulation and coding should comply with existing applicable data encoding standards.

WG1-2 The architecture, data encapsulation and encoding should align with the OSI model.

WG1-3 The data encapsulation and encoding should be able to accommodate various media standards.

WG1-4 The data encapsulation and encoding should allow for the efficient representation of data.

WG1-5 The data encapsulation and encoding should be flexible to allow for alternate representations.

WG1-6 The data encapsulation and encoding should permit the specification of an arbitrary level of precision.

WG1-7 The data encoding should permit the representation of text in all languages supported by the ISO character set encoding standards in such a manner that the data is not region-dependent.

Data Model

Specification Method

WG2-A.1 The specification must make use of informal, natural language descriptions.

WG2-A.2 The conceptual schema of the model should be able to be addressed informally by E-R (Entity-Relationship) diagrams or other comparable graphical means.

WG2-A.3 The specification should include a formal description of the syntax.

WG2-A.4 The specification should be capable of including semantics.

WG2-A.5 The specification should include a formal description of the semantics.

Purpose

WG2-B.1 The model must be enabling.

WG2-B.2 The model must be able to carry any kind of geomatics data.

WG2-B.3 The model should be suitable for handling update requirements.

WG2-B.4 No special structures should be defined to handle archiving. The primary objective is data transfer.

Architecture

WG2-C.1 The architecture should impose media independence.

WG2-C.2 The architecture should insure independence between model specification and implementation (encapsulation and encoding).

WG2-C.3 The architecture should be such that formal checks of data integrity (conformance to the model specification, including syntax and semantics) are possible.

WG2-C.4 The architecture should make use of plug-to-plug compatibility and plug-to-plug replaceability, with a limited number of options for each plug.

WG2-C.5 The architecture should be designed to meet the requirement of extensibility. That is, it should be realistic to add different data constructs and different types of data as the need arises.

WG2-C.6 The architecture should enforce upward compatibility.

WG2-C.7 The architecture should enforce the detection of downward compatibility, to the extent possible.

Overall Model

WG2-D.1 The model defines the use of profiles, to indicate the way in which a given user has structured or defined the data for the transfer.

WG2-D.2 The overall model should have at least the following compatible but replaceable model components: feature identification, geometry and attributes.

WG2-D.3 The model should allow the sharing of components (feature identification, geometry and attributes) between objects.

WG2-D.4 The model should not impose the sharing of components (feature identification, geometry and attributes) between objects.

WG2-D.5 Differences in geometry, features, or attributes result in different geographic objects. Where such objects are related, the model should provide relationships indicating this.

WG2-D.6 The model should recognize composite objects, where one object is composed of other objects and also consists of it's own feature identification, geometry, and attribute descriptions.

WG2-D.7 Representation should be decoupled from the model specification .

WG2-D.8 The model should recognize NIL as valid value everywhere in a transfer.

Geometry

WG2-E.1 The geometric sub-model should include the following named objects defined as primitives: point, arc (line), area and pixel.

WG2-E.2 The geometric sub-model should include the following named objects defined as amalgamation of primitive objects: irregular group of points, a regular group of points or a grid of points, a group of areas, a regular group of pixels, and an irregular group of pixels.

WG2-E.3 Named geometric objects must exist for the concepts of graphs.

WG2-E.4 The definition of a geometric object must include both its component parts and any relevant constraints.

WG2-E.5 The model should be able to handle composite geometric objects.

WG2-E.6 Composite geometric objects may be composed of simpler geometric objects of the same dimensionality or of differing dimensionalities.

WG2-E.7 The model should support volumes and 3-D manifolds will be able to be addressed as the requirement arises.

WG2-E.8 Time should be included as part of the coordinates (X,Y,Z,time).

WG2-E.9 The model should allow for the coordinates to be expressed in the following projections: Transverse Mercator, Lambert conformal, polyconic, etc.

WG2-E.10 The model should not be restricted to a finite list of projections, but should allow for new projections to be defined and used by the user.

Topology

WG2-F.1 It should be possible to have no topology whatsoever.

WG2-F.2 It should be possible to have topology without location data (coordinates).

WG2-F.3 The degree to which topology is used should be stated explicitly.

WG2-F.4 Explicit topology should be able to express the following phenomenon: inside of, contains, on the side of, on the start side of and on the end side of.

WG2-F.5 Explicit topology should be able to express the following phenomenon: overlap and intersection.

WG2-F.6 The notion of identity should be included within the overall model, but not specifically as topology.

Relationship

WG2-G.1 It should be possible for the user to define his or her own set of explicit relationships between objects, additional to the existing relationships in the model specification.

WG2-G.2 Within the overall model, geo-coincidence and neighbourhood should be addressed.

Attribution

WG2-H.1 Attribute choice and definition should be able to be defined by the user.

WG2-H.2 The ways in which the attributes may be structured will be defined by the specification.

WG2-H.3 The attribute portion of the model should be able to handle standard relational structures.

WG2-H.4 The user should be able to use his or her own schema for attribution, as long as the guidelines for structuring are followed.

WG2-H.5 The following data types should be defined and available for domain of attributes: real (float), integer, boolean, character string and octet string.

WG2-H.6 In addition to the previous data types, the following should also be defined and available for attribute domain: unformatted bit stream, voice, raster image, time.

WG2-H.7 In addition to the existing data types, the user should have the ability to formally define his or her own data types.

Metadata

WG2-I.1 The following geomatics metadata should be standardized within the model specification: source, method of capture, coordinate system, datum, data quality, security, references to underlying documents, legal issues, measurement.

WG2-I.2 Metadata, such as described in WG2-I.1, may pertain to all or part of the data in a transfer, including individual geographic objects as required.

WG2-I.3 Some metadata may be defined by the user; thus, provision should be made for the user to do this.

Toponymy and Labels

WG2-J.1 Toponymy and labels must be able to be handled by the model; however, they may be treated differently.

WG2-J.2 Text characteristics must be addressed in a standardized fashion.

Feature Identification

WG3-1 A feature identification model should be clearly identified.

WG3-2 This model should be independent of but compatible with the data model; that is, it should be a submodel of the overall geomatics data model.

WG3-3 The feature identification model should be scale and representation independent.

WG3-4 The feature identification model should not impose a strong hierarchy in the classification scheme.

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Setting the Stage for Data Sharing in British Columbia

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Abstract

The Government of British Columbia, having identified the importance and need for data sharing in managing our provincial resources, has given the Ministry of Crown Lands the responsibility of consolidating mapping services and developing a land related data sharing mechanism for British Columbia.

The Government Corporate Land Information Strategic Plan, completed in July 1988, provides the direction for developing this mechanism to enhance the sharing and exchange of digital land information across the province.

Implementation of this plan has begun, and government ministries and the private sector are being consulted and involved in its development. The initial projects are focusing primarily on the technical issues of data exchange, as well as the standards, guidelines, and policies required to manage the retrieval, exchange, and archiving of this data.

Introduction

Land related data is a vital resource, key to effectively managing British Columbia's natural resources. Objective and timely decisions regarding these natural resources hinge on quick and easy access to accurate and current land related data.

GIS technology is now able to provide us with sophisticated decision support systems. However, from a corporate perspective, data management practices have not kept pace with technological developments. This issue is compounded by single purpose program initiatives, leaving government with growing stockpiles of land related data that are not accessible or sharable, and in many cases lack integrity. This situation needs to be overhauled if we are to improve the management of British Columbia's natural resources and meet the challenge of sustainable development.

Recognizing this, the Government of British Columbia is committed to optimizing the use of the land related data resources within government by enhancing the sharing of and access to this data.

In meeting the challenge, an inter-agency committee, the Corporate Land Information Strategic Committee (LISC) has been formed to provide a forum for discussion, and the Ministry of Crown Lands has been charged with the mandate of coordinating government mapping services. It is under this mandate that the Ministry of Crown Lands developed the Corporate Land Information Strategic

Plan (CLISP), the government-wide strategy for sharing of digital land information.

The CLISP Strategy

Endorsed by Cabinet in 1989, the Corporate Land Information Strategic Plan identifies the technical means, the management process and the organisational structure required to effectively manage the sharing and exchange of government land related information. The intent is to enable the sharing of provincial land related data while ensuring that ministries retain control over their respective data.

The Corporate Land Information Strategic Plan identifies three major deliverables to be put into place over the next four years. The first deliverable, to provide the organizational structure required to assist the Ministry of Crown Lands in carrying out its lead responsibilities for land information in government, has been completed. The second deliverable is the Land Information Management Framework, which is to provide the management requirements needed to support data sharing. The final deliverable is the Land Information Infrastructure, a mechanism comprised of data, applications, and technology within which land related systems can evolve within government organizations, and which facilitates both the internal and external data access and exchange requirements of these organizations.

Organisational Structure

The Corporate Land Information Strategic Plan is being implemented under the guidance of an inter-agency committee, the Land Information Strategic Committee (LISC). This committee and associated sub-committees provide the vehicle to deal with negotiations and decisions necessary to develop a unified view of land information in British Columbia.

Government-wide input into the development of land related data sharing is achieved through representation from the B.C. Assessment Authority, and the Ministries of Forests, Energy Mines and Petroleum Resources, Environment, Crown Lands, Transportation and Highways, Government Management Services, Agriculture and Fisheries, Finance and Corporate Relations, Advanced Education Training and Technology, and Municipal Affairs Recreation and Culture.

Legislative support has been provided through amendment of the *Land Act*, giving the Ministry of Crown Lands the responsibility to set standards for land related information systems in British Columbia. Based on this new responsibility the Ministry of Crown Lands formed the Government Land Information Data Exchange (GLIDE) Unit within the Surveys and Resource Mapping Branch to manage the development and implementation of the Corporate Land Information Strategic Plan.

Over the past couple of years, government has made significant headway in ensuring a coordinated approach to systems development across agencies, through the efforts of the Treasury Board. Cooperative support is being established between the Treasury Board and the GLIDE Unit to ensure the coordinated development of land related information systems in government.

The Means of Sharing and Exchange

Central to the CLISP strategy is the development of the Land Information Infrastructure (LII). This will be the actual means by which ministries, and eventually the private sector, will share and exchange land related data.

Comprised of data, systems and networks, the Land Information Infrastructure will enable users to access distributed and corporate databases through a 'common window'. Access to these databases will be via existing government communication networks. Data viewing, browsing and ordering will be on-line while delivery will be on conventional floppy disks or magnetic tape. The extended vision is that the delivery of data will also be on-line.

Resident in the Corporate Domain, or hub, of the Land Information Infrastructure will be the Corporate databases and the management systems needed to manage access to, and the archiving and exchange of government land related data as shown in Figure 1. The corporate databases which have been identified as being within the Corporate Domain are:

1. The LII Repository, which is to include an LII Directory and the Corporate Dictionary. The LII Directory will provide the information necessary for users to acquire government land related data to meet their specific needs. The Corporate Dictionary will further define and describe the data within the Corporate Domain;

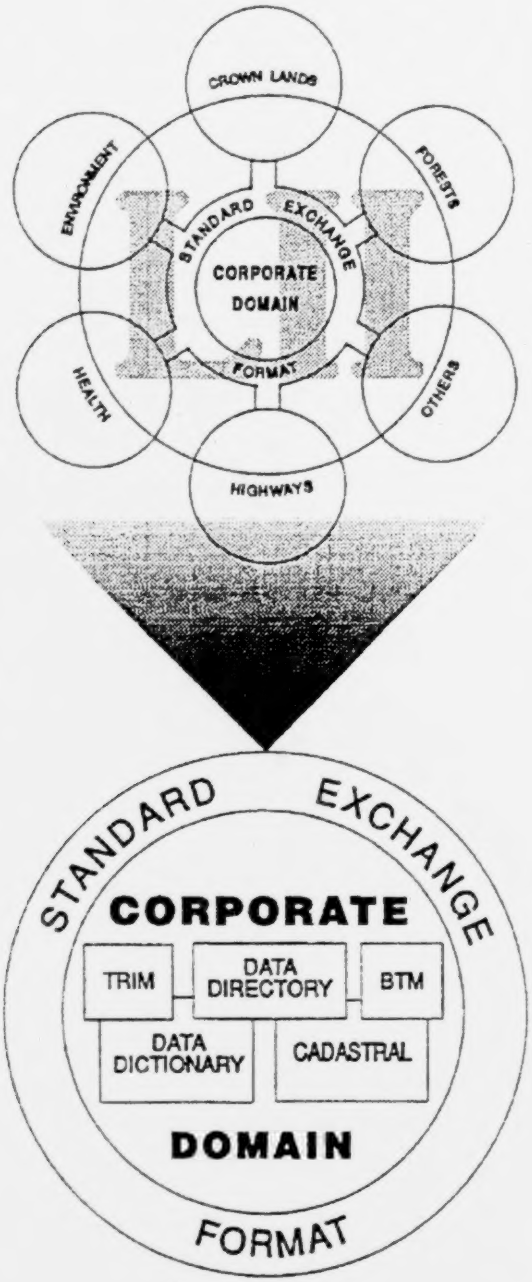
2. Digital topographic baseline information at scales of 1:20 000 (TRIM - Terrain Resource Information Management), 1:250 000, and 1:2 000 000 which will make up the B.C. Digital Atlas. These databases, based on the NAD83 (1983 North American Datum) geodetic reference system, will provide the government standard georeferencing base for all land related data capture identified as being within the scope of the Land Information Infrastructure;

3. Digital Cadastral and General Administrative Boundary data; and,

4. Provisionally, Baseline Thematic Mapping (BTM), which is proposed to contain three thematic levels (ground cover, present land use, and topographic features) derived from satellite image data and digital elevation models.

Building the Land Information Infrastructure (LII)

The actual construction of the Land Information Infrastructure has begun under a four year multi-million dollar contract that will deliver the central hub of the Land Information Infrastructure, the Corporate Domain. This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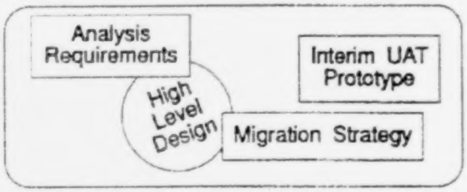
TRIM
DATA DIRECTORY
BTM
DATA DICTIONARY
CADASTRAL
DOMAIN
FORMAT

Figure 1: Conceptual Model of the Land Information Infrastructure (LII).

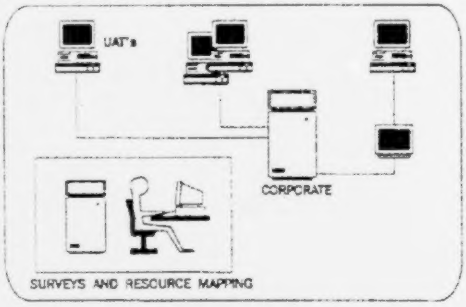
includes the management systems, LII Repository, user access terminals and specifications, plus the specifications for future integration of distributed ministry databases. These developments will move the Land Information Infrastructure from concept to reality.

The management systems will support the integration and management of the Corporate Database to enable access to the LII Repository and corporate data (e.g., TRIM), and facilitate the sharing and exchange of distributed land related data.

The User Access Terminals (UATs) will provide common window access to the corporate databases and distributed ministry databases. Users will be able to access a central ordering facility to view and browse data, and place orders. This will be possible from various personal computers, work stations, and mini-computer terminals supporting various land related information systems' applications (e.g., GIS) in which the data can be used. In addition, specifications will be established to act as 'blueprints' for integrating other hardware/software platforms in the future.


Analysis Requirements
High Level Design
Interim UAT Prototype
Migration Strategy

Phase 1: Design


UAT's
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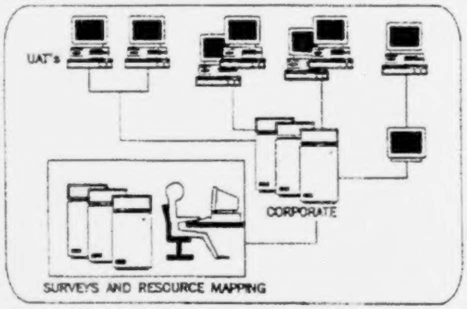
SURVEYS AND RESOURCE MAPPING

Phase 2: Prototype Development


UAT's
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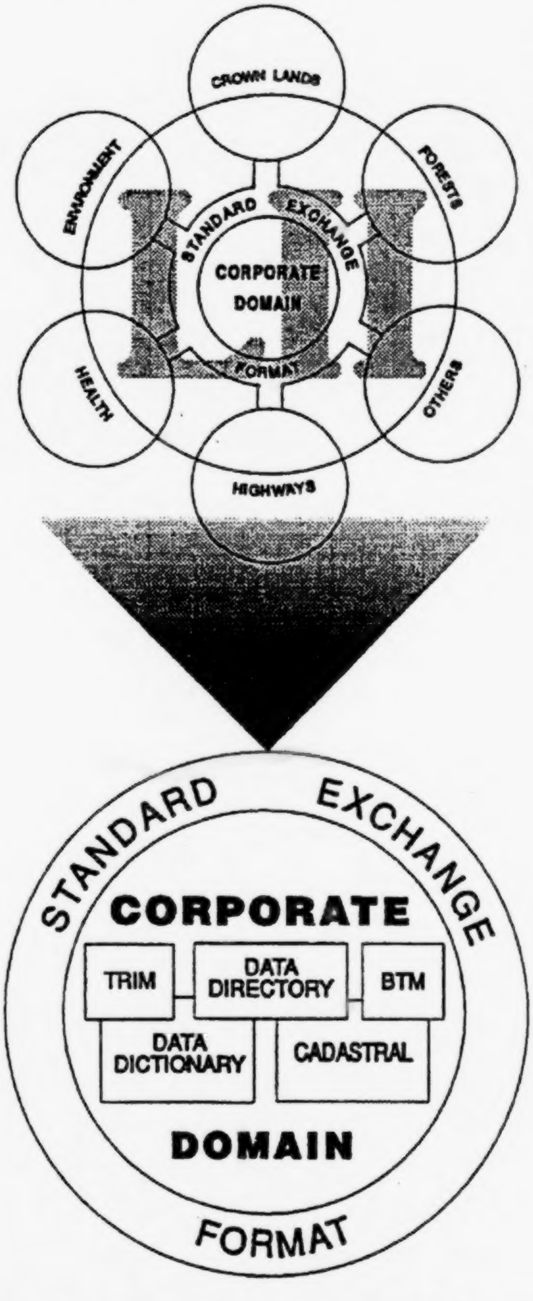
SURVEYS AND RESOURCE MAPPING

Phase 3: Operation and Implementation

Figure 2: Land Information Infrastructure Development Phases.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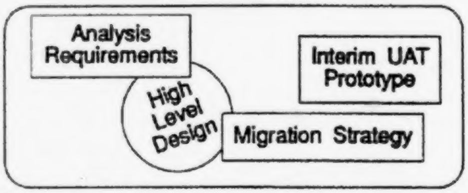
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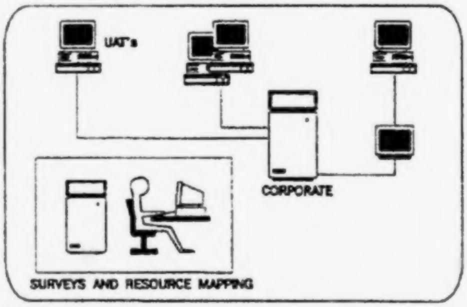
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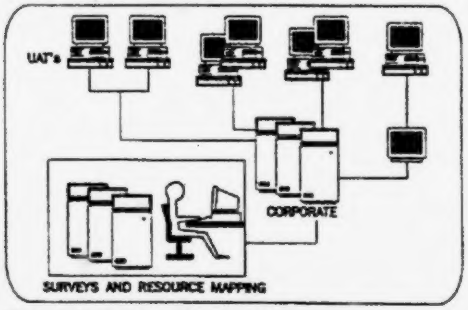
UAT's
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Phase 3: Operation and Implementation

Figure 2: Land Information Infrastructure Development Phases.

These central components of the Land Information Infrastructure will be delivered in four phases, of which, only the first two will be within the scope of the present project:

Phase I will involve determining what the Land Information Infrastructure will look like, and how it will work. Technically speaking, a requirements analysis will be undertaken to establish a conceptual design, migration strategy, and high-level design of the complete Land Information Infrastructure. This includes prototyping of User Access Terminals to assess user requirements and needs.

Phase II will consist of the construction and evalustion of the Corporate Domain prototype, including the LII Repository, plus a data ordering and translation facility. This prototype will be operational, enabling user access queries, browsing and data ordering, data delivery, and data translation from a variety of hardware and software platforms, including GIS. As in Phase I, feedback from users of the User Access Terminals will be evaluated to assess key architectural and performance issues.

Phase III will build on Phase II to provide a fully operational version of the Corporate Domain. Specifications to facilitate the integration of ministry databases within the Land Information Infrastructure will be developed. Additionally, services associated with operations management, order accounting, and the integration of information providers will be accomplished.

Phase IV will be the ongoing expansion of the Land Information Infrastructure to include public and private sector user terminals and the integration of distributed ministry databases. The full realisation of the target system is expected to require ten years. Due to the nature and magnitude of this complex system, however, the Land Information Infrastructure should be viewed as a system that will develop and evolve for many years to come. Figure 3 depicts the target system.

Managing the Land Information Infrastructure

The management of the Land Information Infrastructure, including the data, systems and networks, is supported by the Land Information Management Framework (LIMF). This document contains the policies, standards, guidelines and procedures required to:

1. guide ministries in developing land related information systems such as GIS, to ensure compliance and compatibility with the Land Information Infrastructure;
2. promote the adoption of consistent data management standards and thus promote the sharability of land related data;

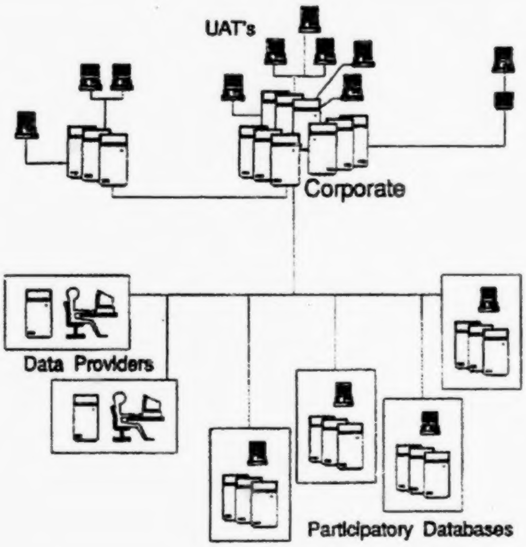

Figure 3: Land Information Infrastructure Target System

3. ensure the consistent and effective use of the data, applications, and technology within the Land Information Infrastructure;
4. enable exchange of land related data between ministries while ensuring data integrity; and,
5. provide the management framework to support the Land Information Infrastructure.

The LIMF is applicable to all land related data, that is, georeferenced data, in the Government of British Columbia. It clarifies the authority, responsibilities and roles of the various players involved in the Land Information Infrastructure, and identifies the requirements for cross-government land related data management, including standards for georeferencing and exchange. In order to aid land information systems development, particulary as they relate to the Land Information Infrastructure, the LIMF outlines requirements for systems planning, development, and operation.

The first version of the LIMF has been released. Since the Land Information Infrastructure is not yet built and the target architecture not determined, this version is at a relatively high level. However, it does indicate the direction in which the government is moving to achieve the goal of land related data sharing in British Columbia, and it provides useful guidance for Land Information Systems development.

Identifying Implementation Issues

No matter how clear and convincing a new concept and approach may be in any large organization, the selling and implementation phases do not come without their problems and roadblocks. As expected, the problems encountered have included funding, commitment, and confusion over ownership, authority and responsibility.

The significance of a corporate approach to data resource management and the impact of GIS and LIS on ministry and government business is still not fully appreciated. Instead, there exists a pioneering approach to the acquisition of technology, with limited consideration given to business objectives and long term program and government data needs. In an attempt to resolve this, the recently published LIMF provides guidance in developing land-related information systems in a manner that is consistent with the Land Information Infrastructure initiative.

Understandably, there is sometimes a reluctance to embrace the idea of corporate or government-wide data sharing because of its impact on existing operations, the necessary re-allocation of scarce resources, and its perception as a relinquishment of power. However, the CLISP strategy proposes that ministries retain control over their respective data. A corporate approach is also identified as a means to reduce data acquisition and management costs and improve data integrity.

Resolving the Issues

There are many organisations, both public and private, which have a stake in the development of the Land Information Infrastructure. It is therefore important that they be informed and consulted throughout the development of this provincial land related data sharing system. In support of this, the Government Land Information Exchange Unit (GLIDE) of the Ministry of Crown Lands has developed a communications plan to inform and educate ministries and interest groups about CLISP developments and deliverables.

Inter-agency committees like the Land Information Strategic Committee have been established to ensure ongoing input from ministries regarding the implementation of CLISP. Also, the Ministry of Crown Lands intends to continue to provide a supporting role in the development of land related information systems.

Conclusion

British Columbians face increasing pressure on the province's natural resources. Effective and objective decisions for integrated resource management hinge on easy access to accurate and current information. The Government of British Columbia, identifying the importance of data and the sharing thereof, is committed to implementing the government strategy, the Corporate Land Information Strategic Plan. A plan that is to support future GIS applications and technological developments.

Concurrent Session 4

Forest Management - Industrial Experiences II

Washington DNR's Forest Management Tracking System: a Design for the Many-to-many Relationship

The Plonski Forest Management Decision Support System

Relating Access Routes to Canada's Forest Inventory in a Geographic Information System

GIS'91

Symposium

Vancouver
British
Columbia
February 1991

Washington DNR's Forest Management Tracking System: A Design for the Many-To-Many Relationship

Steve Miller

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Olympia, Washington

Abstract

In order to manage Washington's state forestlands for sustained long-term yield, the DNR (Department of National Resources) must track its silvicultural and harvest activities and model their effects upon the current and future forest inventory. Several factors have influenced a non-traditional data design for tracking these activities. One factor is that many management activities affect the forest inventory, and must therefore update inventory data. Secondly, many activities either follow or define forest inventory stands, resulting in a high percent of coincident arcs. A third is that there are many-to-many relationships between forest stands and management activities. In other words, there are many historical activities recorded for one timber stand, while certain activities, such as aerial fertilization, apply to more than one stand. Finally, each activity requires a different set of tabular data to be recorded with it.

This presentation discusses a design to overcome these anomalies.

Introduction

Spatial data design has traditionally assumed a one-to-one relationship between spatial features and their associated descriptive (tabular) records. One point, line or polygon feature in the spatial file has exactly one record of tabular data in the feature attribute table.

Within this design, time is static. A feature's tabular record can describe either how it was (once), how it is now, or how it is planned to be at one point in time, but cannot readily describe its various states as time passes.

With the introduction of relational capabilities for spatial data, one need not store all data pertaining to a feature in the feature attribute file. But the limitation remains, that one spatial feature can only be associated with one related record.

Project Background

The Washington Department of Natural Resources (DNR) manages 2.9 million acres of Washington state trust land for the sustained benefit of various state institutions. 71 percent of the trust is classified as forest land with nearly 90 percent of total DNR revenues coming from timber sales.

In order to manage these vital forest resources the DNR has collected, in its GIS, land use and land cover information for all Washington state surface trust lands. A majority of this data consists of summary inventory information for 35,750 timber stands throughout the state. This data includes stand age, primary, secondary and tertiary species, average basal areas per acre, average dbh per acre, management regime, damage type and intensity, etc.. Individual (township) coverages are updated nightly, as updates are received from managers in the field.

The DNR also needs to track timber management activities,past, current and planned , and to be able to apply geographic modeling to this activity data. Pre-commercial thinning, fertilization, planting, site preparation for planting, vegetation control, and planned harvests are all examples of management activities.

This need for activity tracking introduces the dimension of time to X-Y location data; it means that for a given spatial feature record (timber stand polygon), multiple tabular activity records are required. For each stand or polygon, there will be many records of historic activities, as well as records of activities planned for the future.

Conversely, there are situations wherein one tabular activity record relates to multiple polygons. An example would be an aerial fertilization activity covering many timber stands. The result is a many-to-many relationship.

A further design consideration is that some activities effect an immediate change to the timber stand(s) they are performed on. Examples are pre-commercial thinnings, clearcut harvests, or initial planting activities. This dictates a very close linkage between two sets of data, originally conceived as two layers.

In researching the expected applications of activity information, it was realized that most use would be in conjunction with stand inventory data. Questions like 'Where are 15 to 20 year-old true fir stands (inventory) which have not yet been thinned?' would be common.

Finally, because many management activities, such as thinning, harvesting, site preparation and seeding, either follow existing stand boundaries, or define future stand boundaries, there is a very high coincidence of arcs between the activities and the stand inventory data layers.

As the list of design considerations grew, there was increasing recognition of the potential complexities; a concern was that a highly complex system would have greater support and maintenance costs. What was sought was a relatively simple conceptual design, which could accommodate the known complexities, and anticipate future requirements.

Data Design

The design developed to address these requirements necessarily deviates from the traditional concept of one data layer per theme, and one tabular record per spatial feature record.

It was first decided that activities reporting and stand inventory update should be integrated into one system; the activity reporting system would be the process by which stand inventory data is updated. This would preclude field foresters and data entry staff from having to learn and contend with two different update processes and it would ensure integrity and consistency between the two data sets.

A coding system was developed wherein anything that changes a timber stand's characteristics could be reported and entered as an activity. The coding system design is open-ended, to accommodate future management activities which may or may not be forestry related. The recording of certain activity codes, such as a clearcut timber harvest, would trigger specific updates to the inventory data for the stands involved.

Because of the update interdependencies and the high coincidence of spatial features, it was decided that the optimal design would spatially combine the stand inventory layer with the activities layer. This approach has the disadvantage of becoming spatially very busy. When multiple themes are combined, the separate identities of each (stands vs activities) must still be maintained. The ability to suppress certain data, via the ARCPLOT DROPLINE command, for example, becomes very important. The significant advantage is that this initial combining eliminates the problems of duplicate, coincident arcs in two different layers, and the significant slivering problems encountered when two layers must be intersected for updating. There are other advantages as well: it virtually eliminates redundant tabular data by combining data that will most often be used together later; and it precludes the need for extensive linkage programs, to monitor the activity layer and trigger appropriate inventory updates.

Finally, the problem of the many-to-many relationships is one that can only be resolved by use of a cross-reference file, between the feature attribute table (ARC PAT file), and various thematic extension files. Essentially, this requires relating the activity/polygon cross-reference file to the PAT via an unique polygon ID, and then relating the activity extension file to the cross-reference file via an activity ID unique to an activity event.

Unfortunately, ARC's relational capabilities do not go beyond the first relational level; thus one cannot relate through one file to another. An essential element in our design was the development of in-house programs to extend ARC's relational capabilities beyond the first relational level. A further limitation of ARC relates is that if two or more records in the related file match the current PAT record, only the first related record is read. Additional software was written to accomplish next related record processing.

Figure 1 illustrates an example of the spatial LULC (Land Use/Land Cover) data layer.

Note that stands 03 and 04 (upper left) were both included in one activity (activity number 35), which happened to be a forest maintenance - vegetation control activity. This exemplifies the multiple-stands-to-one-activity situation.

Stand number 07 (upper right) has two activities (36 and 37) recorded for it, splitting the stand into three polygons.

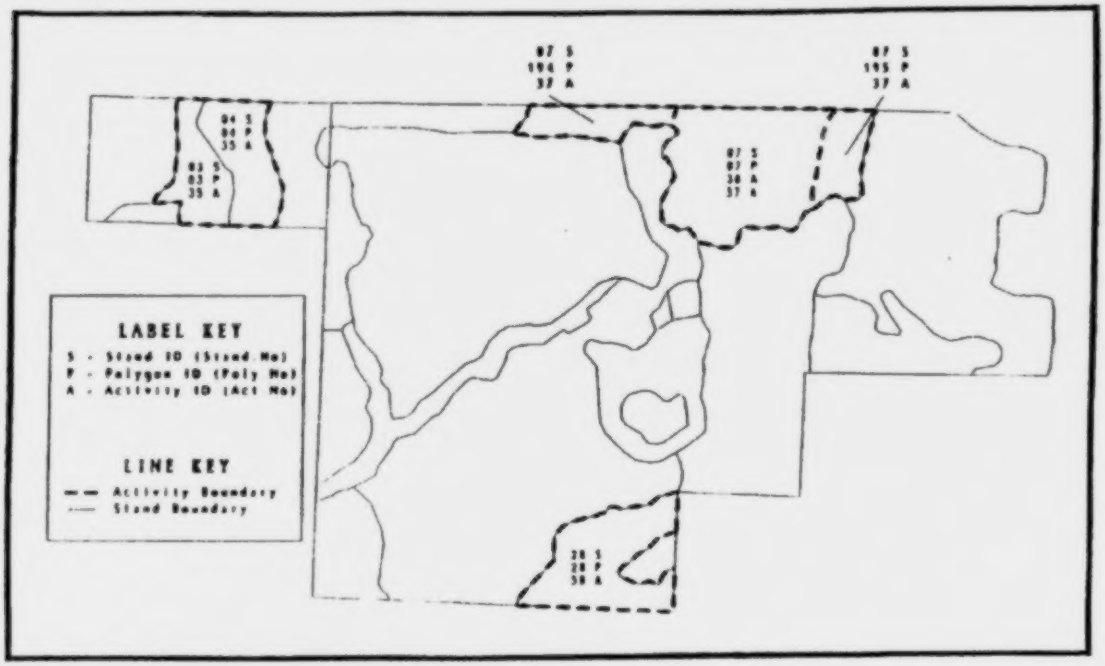
07 S
194 P
37 A
07 S
195 P
37 A
04 S
04 P
35 A
03 S
03 P
35 A
07 S
07 P
36 A
37 A
LABEL KEY
S - Stand ID (Stand.No)
P - Polygon ID (Poly No)
A - Activity ID (Act No)
LINE KEY
Activity Boundary
Stand Boundary
28 S
28 P
58 A

Figure 1

This stand illustrates one-stand-to-multiple-activities. Within stand 07, polygon 07 shows one-polygon-to-multiple-activities.

Finally, stand number 28 (lower center) has a conventional one-stand, one polygon, one activity relationship.

Figure 2 shows the relationships between stands and polygons in the LULC (Land Use/Land Cover) PAT. Notice again that stand number 07 consists of three polygons (07, 194, and 195).

```
ENTER COMMAND >LI POLY.NO,STAND.NO
   $RECNO      POLY.NO     STAND.NO
         .     .......     .......
         .     .......     .......
         3     3390003     3390003
         4     3390004     3390004
         .     .......     .......
         .     .......     .......
         7     390194      3390007
         8     3390007     3390007
         9     3390195     3390007
         .     .......     .......
         .     .......     ......
         .     .......     .......
        27     3390028     3390028
```

Figure 2

Figure 3 illustrates the activities cross-reference file, which consists of only two items, the unique polygon ID and the unique activity event ID. It is sorted on POLY.NO, so that it can be related to the PAT with the ORDERED option.

```
ENTER COMMAND >SEL ACT.CROSS
ENTER COMMAND >LI
  $RECNO      POLY.NO     ACT.NO
        1     3390003     3390035
        2     3390004     3390035
        3     3390007     3390037
        4     3390007     3390036
        .     .......     .......
        .     .......     .......
       11     3390028     3390058
        .     .......     .......
        .     .......     .......
       76     3390194     3390037
       77     3390195     3390037
```

Figure 3

Note that polygon number 07 is recorded twice, since there are two (tabular) activities associated with it, and that activities 35 and 37 occur more than once, since each is associated with multiple polygons.

Figures 4 and 5 illustrate two typical reports summarizing the data portrayed in the examples.

General
Forest Management Activity
Report

Washington Dept. of Natural Resources

ACTIVITY NUMBER	ACTIVITY TYPE	MO	YR	ACTIVITY METHOD ACRES	TOTAL TREATED BY:	ACTIVITY PERFORMED USE	CURRENT LAND ACTIVITY	5X NEXT MO.	FUT. ACT. YR.	FUT. ACT.
3390035	FOR VEG CHEM	7	1985	AERIAL SPRAY	76	CONTRACTOR	NO DATA	PCT	3	1990
3390036	FOR PRP CHEM	6	1986	AERIAL SPRAY	32	CONTRACTOR	DF-INT-W/T		0	0
3390037	ST TRE PLG	2	1987	NONE	60	CONTRACTOR	DF-INT-W/T	FOR VEG CHEM	5	1990
3390058	FOR PRP CHEM	9	1988	AERIAL SPRAY	30	CONTRACTOR	DF-INT-W/O	0	0	

Figure 4

Primary Species Report
for Even Age Management

Washington Dept. of Natural Resources

STAND NO.	TOWN SHIP	RANGE	SECT	LAND USE	DNR LOCAL UNIT	DNR SURFACE TRUST	PRIM SPEC	PRIM SPEC ORIGIN	PRIM BA /ACRE	PRI STEMS /ACRE	PRIM SPEC DBH	MAP ACRES
3390003	11	2 E	4	DF-INT-W/T	WINLOCK	3	DF	1976	0	350	1	14.39
3390004	11	2 E	4	DF-INT-W/T	WINLOCK	3	DF	1973	0	300	3	18.47
3390007	11	2 E	2	DF-INT-W/T	WINLOCK	7	DF	1987	0	3500		1.50
3390007	11	2 E	2	DF-INT-W/T	WINLOCK	7	DF	1987	0	350	0	10.95
3390007	11	2 E	3	DF-INT-W/T	WINLOCK	2	DF	1987	0	350	0	11.06
3390007	11	2 E	3	DF-INT-W/T	WINLOCK	2	DF	1987	0	350	0	47.44
3390028	11	2 E	3	DF-INT-W/T	WINLOCK	2	CC	0	0	0	99	30.42
				DF-INT-W/T								134.23
												======
												134.23

Figure 5

Status and Future Development

The Forest Management Activity system was integrated into the Washington DNR's GIS in the summer of 1987 and has been very successful. On average, nearly 50 new activities per week are added to the database. The design is open-ended, for inclusion of additional types of activities as needed.

A recent inclusion to the activities system has been the incorporation of a timber pre-sales tracking system, wherein planned timber sale units are digitized into the LULC spatial layer, and receive timber pre-sales activity codes. The design has also anticipated forest regeneration plans, which are required before a unit can be sold. Initial development has begun to include harvest planning data, involving plans extending 5 to 10 years into the future. This will allow field managers to test hypothetical management scenarios and to anticipate problems or opportunities.

The design is not orthodox, and DNR acknowledges the risks. But there is an unrelenting need to push the limits of GIS technology. In so doing, we must be ever willing to re-evaluate the conventional wisdom and traditional design approaches.

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The Plonski Forest Management Decision Support System Project

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Abstract

The focus of a decision support system is much different from traditional Management Information Systems (MIS) and data-based 'decision support systems'. Decision support systems, as defined by the authors, focus on decisions and decision makers, and on information. Technology is treated as a tool and data as the raw material. In many traditional systems, the focus is on the technology, and the data is the 'information', while decision makers are, to some extent, externalized.

The purpose of the Plonski Forest Management Decision Support System (FMDSS) project is to develop a set of software tools for creating forest management decision support systems. This set of tools will be used to implement a prototype forest management decision support system for the Plonski forest, near Kirkland Lake, Ontario.

There are three critical ingredients in building the FMDSS, these are knowledge of the decision making process, knowledge of the forest, and the functionality of underlying support technology. The growing maturity of the underlying technology provides a tremendous opportunity to develop decision support tools. However, a significant obstacle to building FMDSS has been the diffuse nature of knowledge about forest management decision making processes, and about the forest ecosystem itself. Often this knowledge is spread widely among foresters, technicians, policy makers, and scientists, or is in a form that is not easily amenable to the decision support process. This has created a heavy burden on the project team to gather and collate the knowledge so that it could be incorporated into the functions and design of the system. It will be difficult to gauge the success of this exercise until users obtain the software and begin to experiment with its use.

Introduction

Most government agencies and forest products companies utilize various computerized 'information' systems to assist with recording and summarizing a variety of forest management data. In addition, many have implemented GIS systems in order to handle spatial data. However, within the resource management sector, GIS systems have been used primarily as data custodians. The principle focus has been on producing the conventional information products faster and better. As Baskerville and Moore state, "The forest community has tended to automate the old data system rather than redesign it into an information system with the new technology". Each of the various systems may be adequate tools on an individual basis. For many decision makers, however, these systems are disparate, difficult to use, provide insights into data rather than information, and may only offer a single and rather restricted approach to the decision making process.

With this in mind, the Northern Region, Ontario Ministry of Natural Resources (OMNR), in conjunction with ESRI Canada Ltd. have initiated a project to develop a prototype decision support system for timber management. In the decision support system, GIS will be utilized as an advanced tool for the forest manager on the Plonski Forest, Kirkland Lake District.

The system will be tested on the Plonski forest, Kirkland Lake District. The Plonski forest was chosen for its convenient size and location, its extensive database, its complex mix of mills and products, and its history of intensive and progressive forest management. In essence, the Plonski Forest is a provincial model for boreal forest management and provides a broad range of challenges for the decision support system.

Software development is scheduled to take place over a three-year period, from 1990 to 1993. An additional one-year period has been set aside for the Ministry of Natural Resources to transfer the technology to other offices across the province.

Although the project will be completed after 3 years, the need for development will not end there. Any system that supports decision making will necessarily evolve in response to changes in the decision process. For this reason, the Plonski Forest project should be seen as a platform for the development and testing of new decision support system tools and techniques.

Goals and Objectives

Goals

Ontario Ministry of Natural Resources - Northern Region

To develop a decision support system to improve the quality of the timber management planning process in the Northern Region of the OMNR, and to lead the way in the transfer of this technology to other forests in the province.

Environmental Systems Research Institute Canada

To develop a set of marketable software products for building forest management decision support systems in other jurisdictions and private companies.

Objectives

Ontario Ministry of Natural Resources - Northern Region

To develop and test a prototype decision support system that will facilitate efficient and effective timber management planning on the Plonski Forest by meeting the following criteria:

- allowing for the evaluation and comparison of multiple scenarios for long term management decisions on wood supply, wildlife habitat, and other forest uses;
- allowing for the explicit evaluation of important management option;
- allowing for the for interactive assignment and analysis of forest management activities within a geographically referenced framework;
- monitoring and reporting on management performance with respect to management targets; and
- providing a framework for the decision process as identified in the Class Environmental Assessment for Timber Management on Crown Lands in Ontario.

Environmental Systems Research Institute Canada

To research, develop and market software for implementing forest management decision support systems through:

- identifying generic forest management functions and their parameters;
- designing and developing software tools for implementing these functions;
- developing and packaging a set of application modules for implementing forest management decision support systems using the developed tools;
- developing methods for implementation of the applications at other sites world-wide; and
- developing corporate expertise and training staff to use the developed methods

What is a Decision Support System?

A review of the literature reveals that the term decision support can have many different meanings depending on the author's point of view. People who design and build information systems quite often describe a decision support system in terms of its main software components. For example, Densham and Armstrong suggest that conceptually, a spatial decision support system (SDSS) can be thought of as providing an integrated set of flexible capabilities, the implementation of which are achieved using a set of linked software modules. The main modules that should be present are:

- database management system;
- analysis routines;
- display and report generators; and
- user interface.

This definition does, in fact, cover most of the major software components of FMDSS. However, underlying these design features are characteristics specifically related to how a decision support system could be used in the decision making process. Some of the main characteristics requested by the project's user community are the capabilities to:

- emulate current decision making practices;
- incorporate experience and 'rules of thumb' with the latest scientific research;
- show the potential effects of decisions on the forest and on management objectives for the forest;
- support all levels of decision making from operational to strategic to policy;
- be usable by a decision maker who is not a computer expert;
- support a natural decision making process by being interactive and by conveying information with visual representation; and
- not be a 'black box', but to be a 'decision support' system, rather than a 'decision maker' system.

The focus, from the viewpoint of decision makers, is on the kind of decisions that need to be supported and on how decision makers wish to interact with FMDSS. These characteristics do not in themselves provide specific direction on the technology to be used, but do provide some general benchmarks which are being used in the design of the software modules.

System Functionality

Software Modules

The functionality of the Plonski FMDSS will be contained in four modules. A summary listing of each module and its planned functionality is provided below.

Forest Records Management Module

Database Maintenance
- maintains forest inventory;
- maintains other inventories required to run the models and tools;
- produces the required reports;
- links silviculture assessments with silviculture treatments; and
- maintains details of harvest and silviculture treatments.

Database Query
- ad hoc query by attribute criteria;
- ad hoc query by geographic criteria;
- standard reports and maps; and
- map and report generator.

Image Analysis
- utilizes remotely sensed data to update forest inventory;
- carries out geometric corrections and classifications; and
- provides input data for insect and disease damage, acid rain damage and forest decline.

Data Collection
- schedules data collection and site inspection activities;
- input data required to run other tools and models; and
- performs analysis of input data and updating of database.

Strategic Planning Module

Long term Wood Supply Model
- models growth and depletion through time;
- functions at the stand level;
- links with the wildlife habitat supply model; and
- provides outputs suitable for use by the operations tools.

Wildlife Habitat Supply Model
- links with the long term wood supply model;
- estimates potential supply of wildlife habitat; and
- utilizes habitat components and their geographic distribution.

Risk Management
- assesses risk and/or sensitivity associated with wood supply strategies;
- assess potential impact of loss due to fire, insects or disease; and
- identifies harvest and silviculture scenarios which minimize risk.

Operations Planning Module

Harvest Planning
- short term harvest scheduling;
- road planning, cut block layout; and seasonal woodflow planning;
- planning for other values; and
- feeds results back to long term wood supply.

Silviculture Planning
- crop planning for areas scheduled to be harvested in short term;
- utilizes silvicultural history information to identify the most effective or cost efficient prescriptions;
- assists with the scheduling of equipment and manpower;
- forecasts nursery stock and seed requirements; and
- feeds results back to long term wood supply.

Systems Implementation Management Module

System Administration
- configuration and installation;
- system administration including user accounts, backups, security and database administration; and
- communications and remote access.

User Interface
- design standards;
- viewing data, processes and interfaces; and
- help facilities.

Incorporated into the above functions are three design features which warrant further discussion. These are transaction processing, forest history, and the integration of strategic and operational planning.

Transaction Processing

The Forest Resources Inventory (FRI) of Ontario represents a 'snapshot' of the forest. The FRI is an interpretation of certain aspects of the forest at that point in time when the aerial photography was taken. The FRI is developed on a 20-year cycle and therefore a new 'snapshot' of the forest is produced approximately every 20 years. In field offices where the FRI is used on a daily basis for planning and implementing forest management activities, the geographic extent of real world events such as cutting, site preparation, and planting are recorded on paper copy maps. This is carried out once a year, following the collection of supplemental aerial photographs. In addition, there is a computer-based flat file database for recording changes to stand characteristics. However, there is currently no database in which both the spatial and attribute changes can be recorded and related. There is no easy way of knowing, during the course of the year, how much work has been completed, of what nature, or where activities have taken place and by whom. Answers to these questions are compiled, with difficulty, from a variety of sources, on an ad hoc basis.

The use of a GIS provides a good solution to the problem of relating spatial and attribute data, but does little in itself, to track and report on in-year activities and changes to the forest. For this problem, we propose to maintain the forest database through transaction processing.

Transaction processing is a database management term which implies that maintenance of the database takes place as a series of transactions. This terminology comes from the MIS world, where changes to business databases come largely from financial transactions, such as the withdrawal of funds from a bank account. The database is updated through a series of relatively continuous transactions as events in the real world are recorded in the database. The database immediately reflects the impact of the transaction, and any subsequent inquiry would reflect the database after the last transaction. In the maintenance of the forest database, this would mean that activities which managers are aware of would be recorded as they take place, and the forest database would be more or less up-to-date at all times. The frequency of recording transactions could vary widely, but the database would reflect known changes as of the date of the last transaction. This offers tremendous advantages for managers in terms of planning and control on a weekly, or perhaps monthly basis.

In addition, the transaction metaphor could be extended in a future version of FMDSS to include planned activities. Planned activities can be recorded as planned transactions, and then compared to actual transactions in order to audit the implementation of management plans. In this way, managers could track progress in achieving targets during the year, or at any point during the life of a plan. Instead of reacting to a failure to achieve targets, the manager can anticipate and alter plans or targets where appropriate.

Forest History

Adding a temporal dimension to the forest database offers many unique opportunities for decision making. The ability to maintain an historical coverage is achieved through time-stamping. Data is never deleted from the system, and instead the attribute or spatial data is marked with the date at which it is retired. All retired data is then copied to a historical coverage. The user can then recreate the database at any point in time. Although this is an important capability, time-stamped coverages represent only a single point in time, and do not reveal the sequence of events, or history, of the area. Time-stamping provides, in effect, a snapshot in time. The sequence of events on an area is, however, provided by transaction processing.

Transaction processing provides for the recording of all events which change the database in some way. These events are recorded in a transaction table. The transaction table provides the sequence of events or changes to the database. In addition to the transaction table, a related table maintains the history of changes to the geographic entities of points, lines and polygons. By maintaining a 'history of transactions', the user can make queries on the trans-action(s), and on any geographic area related to those transactions. This provides the capability to track all the activities that have occurred on a specific area. Together, time-stamped coverages and transaction history provide the necessary elements for forest history.

Forest history can provide insights into the relationship between management prescription and the subsequent response of the forest to that prescription. For example, the forest database can include the accumulated success rates of each and every prescription and combination of prescriptions on a specific site type. This could provide the decision maker with feedback on what strategies work best on which sites, for what cost and what benefit. This ability will be incorporated into the silviculture planning tool.

An accumulated transaction history will also allow the reconstruction and querying of the forest database as it existed at any point in time. Decision makers will want to investigate the reasons for success or failure on a particular site. Many of the reasons for success or failure can be found in the history of transactions on that site and even in the historical stand structure. For example, the failure of a pine plantation may be attributed to the overwhelming presence of a competing species such as aspen in the original stand, combined with a failure to follow up with adequate vegetation management. However, it may also be that the investment in vegetation management was significant, and that the original prescription for the site was unrealistic. By exploring the history of the site, foresters should be able to learn more about the capabilities and limits of the forest which they are managing.

Integration of Strategic and Operational Planning

Quite often the consideration of long term, strategic goals is quite separate from the planning of on-the-ground operations. The time frame, scope and precision of the two planning levels vary considerably. Nevertheless, actual on-the-ground results will determine the degree of success in achieving long term strategic goals. A manager can set ambitious strategic goals, and then, in a separate process, devise operational plans which will not help achieve those goals, and may in fact hinder their achievement. There is a requirement to examine the potential impact of short term operational plans on long term strategic goals.

The long term wood supply model will look at strategic questions such as the long term, sustainable harvest levels. Considerations at this level of analysis will be on a rather gross scale. For example, access might be incorporated into such a model by identifying one kilometre wide main access corridors and then buffering these corridors by an additional five or ten kilometres to indicate secondary access. With the operational planning tools, the access planning will be much more precise.

In addition, there will be some aspects of harvest and silviculture scheduling not considered by the long term wood supply model, but which form an important component of short term harvest scheduling. For example, seasonal wood flow is a crucial aspect of operational planning, but would not be considered in a long term wood supply model.

As indicated in the above listing of system features, the operational planning tools include a feature which would allow short term harvest and silviculture schedules to feed into the long term wood supply model. By incorporating a feature which allows short term harvest and silviculture schedules to be fed into the long term wood supply model, the decision maker can re-run the model and examine any impact on strategic goals. This process would provide the decision maker with the opportunity to revise operational plans, strategic plans or both to ensure that on-the-ground planning is consistent with long term strategies.

Development Strategies

Existing Software and New Development

The Forest Management Decision Support System will integrate a variety of existing software technologies including geographic information systems, relational database management systems, heuristic and knowledge-based modelling, image analysis, statistical analysis, and text and document processing. Commercial software packages, including ARC/INFO, will form the foundation of FMDSS. This significantly lowers development time and costs, and as much as possible, insures long term viability of the product.

Where commercial software is not available, other existing software will be investigated for potential. Public domain software produced by various research and development efforts is a major source of modelling tools. There have been numerous wood supply models developed here in Canada and the United States which offer significant functionality, and could provide the basis for a wood supply model in FMDSS. In some cases, the use of existing software systems will be in the form of a link with FMDSS. FMDSS will provide the capability to export data to, and import data from, external software systems.

Where existing software systems and models do not offer a viable solution, we are seeking the cooperation of various agencies in joint development efforts.

Much of the in-house design and development will centre on enhancing, integrating and developing a consistent interface for existing software tools. There will also be a significant task in designing and developing the database management tools for maintaining, updating, and querying of the database, and in managing the inputs and outputs of various modelling tools.

Structured Systems Analysis and Design

There are many different approaches to systems development currently in use. There is the 'closet' approach where systems experts build the system which they perceive is what the users really need. This can produce very sophisticated and complex systems with excellent documentation, but very little relevance for the targeted user. Then there is the Nike approach, otherwise known as the 'Just do it' approach. This usually involves some combination of sophisticated user and/or technocrat, who develops a working system based on the true user needs at one point in time. However, the system is usually poorly documented, or not documented at all, requires constant debugging, is not very portable, even on the same platforms and operating systems, and cannot be maintained once the original authors move on to other projects. These systems rapidly become obsolete, unless a major rework is com-pleted, often involving greater resources than used to develop the original system.

In the Plonski project, both the 'closet' approach and the 'Just do it' approach have been rejected in favour of a structured approach to system analysis and design. Structured systems analysis and design is a software development methodology which requires that software development proceed through a series of phases, and produce very specific diagrams and other documentation. Figure 1 illustrates the typical life cycle for software development using the structured design approach. The life cycle begins with a feasibility study, proceeds to functional or system specifications, general design, detailed design, code generation, testing, implementation, and maintenance.

The structured approach to systems analysis and design requires 'engineering' of the system. There is a much stronger emphasis on analysis and design than on code generation. The system functionality, what it will do, and the system design, how it will do it, must be defined in great detail prior to the development of code. Specific diagramming techniques are used to develop the 'engineering blueprints' for the system.

The software development methodology used in the project is a modified version of the above approach. The major modifications to the structured approach will be the development and testing of a prototype prior to proceeding with detailed design work. Secondly, detailed design, coding and testing will proceed in three stages or releases. Each release will consist of some of the functionality indicated in the functional specifications, with progressively more functionality in each subsequent release.

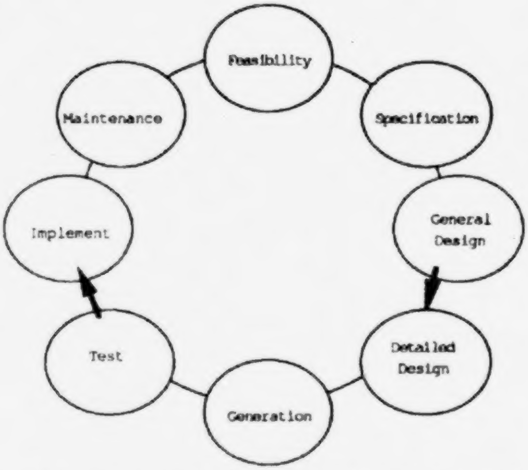

Figure 1. Software Development Life Cycle for Structured Design Approach

The development cycle will be as follows:

Functional Specifications
General Design Specifications
Develop Prototype
Test Prototype
Detailed Design Specifications - release 1
Coding and Documentation - release 1
Testing - release 1
Installation - release 1
Detailed Design Specifications - release 2
Coding and Documentation - release 2
Testing - release 2
Installation - release 2
Detailed Design Specifications - release 3
Coding and Documentation - release 3
Testing - release 3
Installation - release 3
Module Testing
System Integration Test
Sign-off

The most crucial steps in this process are the first few. It is during these steps that the development methodology will be tested and fine tuned. Below is a brief description of these first steps.

Specifications for the FMDSS software will be developed in a two-step process. The first step is the preparation of functional specifications. These specification present the scope of the intended system as perceived by the end users, and define its purpose, constraints, and objectives. The functional specifications are documented in the 'Plonski Book'.

The second step of the development process will be the preparation of design specifications. These specifications will outline how the FMDSS software will operate. They will include the specifications on the type of data required, how the data will be stored, retrieved and used, how the FMDSS modules and tools will be linked together to form an integrated decision support system and a user interface. Design specifications are developed in two phases, the general design phase and the detailed design phase.

The general design phase includes two steps. The first is the generation of a basic design which addresses each topic covered in the functional specifications. It models the system from a data flow viewpoint, but also addresses how data will be processed and used. The second is the generation of a design document which will be a product of this phase, and will be retained for further reference during the project cycle.

Following the general design phase, the project will proceed with the development and testing of a prototype release. The prototype will include some of the functionality of release 1. The purpose in developing the prototype is twofold. First, the project needs user community input that is based on actual experiences with some of the FMDSS tools. This will assist in the refinement of the user interface design, a crucial component of the system. Secondly, this will help identify errors in the functional specifications, and general design work prior to proceeding with the intensive and expensive work involved with detailed design. As illustrated in Figure 2, the cost to fix errors, if found in these early phases of the project, can be significantly lower than in later phases.

Following the development and testing of a prototype, the project will proceed to detailed design. This phase is the detailed analysis and design of those functions isolated in the general design. The detailed design phase includes two steps. The first is the generation of a basic design which addresses each function isolated in the general design, and scheduled for that release of the software. The second is the generation of a design document which will be produced at the end of the detailed design phase for each release of the software. In addition, the detailed design document will be used for future reference during the project and the subsequent maintenance phase.

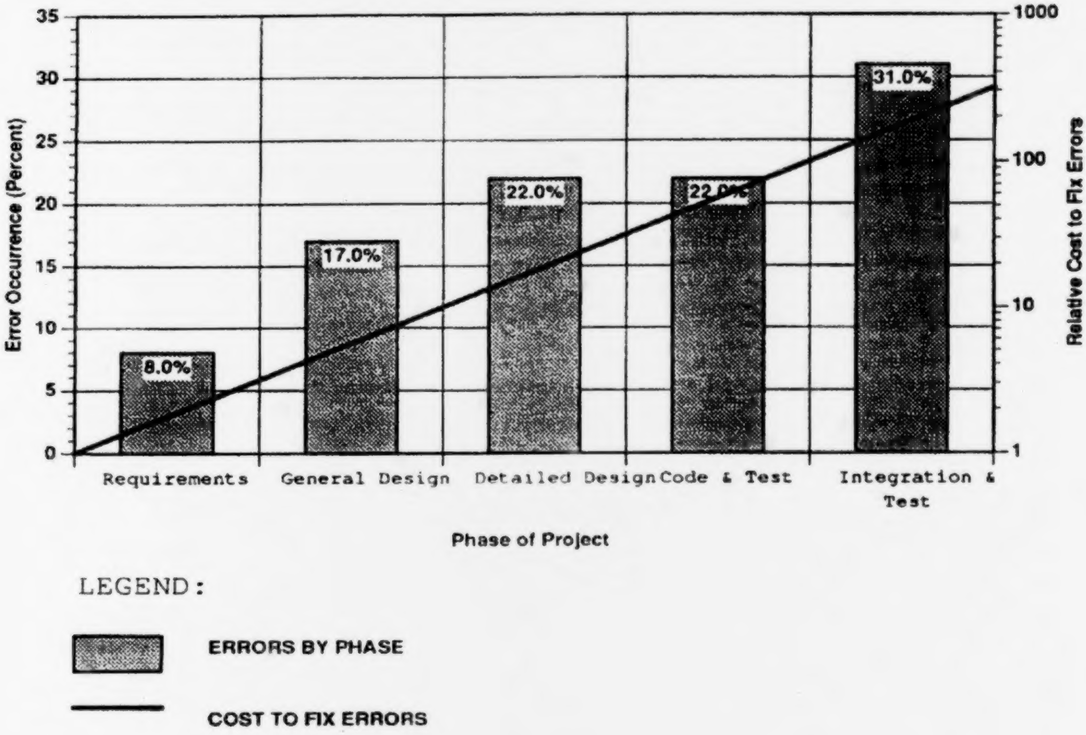

Figure 2. Cost to Fix Errors by Phase

End User Participation

The requirements of the structured design approach put a heavy burden on system builders to decide, in advance, what questions or decisions need to be supported, and what information is required to support them. Only the end user can make these choices. For this reason, a key aspect of our approach to the development process is the intimate involvement of users throughout the software development life cycle.

In order to facilitate user participation the project established development teams consisting of foresters, and domain experts in forest inventory, wildlife management, remote sensing, GIS, wood supply modelling, and silviculture. These development teams will provide most of the input for functional specifications. In addition, they will provide a pool from which the project can draw in establishing design teams, and in providing critiques of the design documents. As the project progresses, development team members will participate in workshops to test and evaluate the prototype release as well as all subsequent software releases. Where facilities exist, some team members will provide test sites for specific modules or components of FMDSS. Finally, development teams provide a forum for the testing and evaluation of existing software models or tools which might be incorporated into FMDSS.

Computer Aided Software Engineering

During the specification and design phases, the project will utilize a CASE (Computer Aided Software Engineering) tool called DEFT™. The DEFT™ CASE tool will be used specifically in the design phases of the project. CASE tools, such as DEFT™, offer several advantages in the design and development of large software projects. Sorensen identifies the following CASE advantages:

- reduces the amount of code required to develop a system;
- increases the quality of applications developed;
- records the thinking that goes into software development in the form of diagrams, models and specifications;
- fills users needs better by providing mechanisms for users to review and critique system design;
- requires system less maintenance;
- completes documentation at the same time as development takes place; and
- significantly reduces documentation time.

The use of DEFT™, in particular, means that the project can support a variety of commercial RDBMS packages on many different platforms.

What We've Learned So Far

Functional specifications for FMDSS were completed in October, 1990, and the project is currently in the general design phase. Over the next six months, the project is scheduled to complete the general design phase, and the development and testing of a prototype release containing some of the functionality intended for release 1.

The development of functional specifications for FMDSS took almost one year to complete. Throughout this process, project staff were adapting to the project's development methodology and learning much about what the users would like to see in FMDSS. The functional specifications exercise was primarily concerned with documenting the decisions that should be supported by FMDSS, and the information that would be required to support those decisions. Since users are the one making the decisions, they were heavily involved in the development of the functional specifications.

A significant obstacle for this exercise was, and continues to be, the diffuse nature of knowledge about forest management decision making processes, and about the forest ecosystem itself. Often this knowledge is spread widely among foresters, technicians, policy makers, and scientists, or is in a form that is not easily amenable to the decision support process. This task was also complicated by the fact that the OMNR is undergoing a major review of forest management practices through the Environmental Assessment hearings.

A series of workshops and mailings generated a wealth of user input centering around the decision making process and information needs. At these workshops, users were combined with domain experts who made them aware of the potential of technology to help them. It was hoped that with an enhanced understanding of this potential, user input would not be limited to suggestions around automating current decision processes.

During the course of developing the functional specifications, the input from the user community dropped significantly in the latter stages of this process. Users found it difficult to be more specific in describing system functionality without concrete products to work with. At the same time, it had to be realized that some decision making would remain difficult to document, and that the FMDSS would have to remain flexible enough to accommodate the varying approaches to decision making.

There were other consequences of this exercise. Our user community developed the expectation that usable software would follow quite rapidly. This expectation was due, in part, to the perception that current technology, such as GIS, could provide most of the capability which users required. The user community, armed with new knowledge about the potential of technology, had to continue to make decisions using current tools and methods. This has, understandably, caused some frustration.

In hindsight, the project might have limited the functional specifications exercise to three or four months, followed by the rapid development of a prototype and further consultation with the user community based on user testing of the prototype. In response to this experience, the project has adopted a modified approach to system design and development, which includes the development and testing of a prototype. The modified approach was described earlier.

Rapid prototyping, on the other hand, can have significant problems. Prototyping costs money, extends development time, and can sometimes be perceived as the final system. In addition, prototypes can build false perceptions about the ease of development.

The following are a few of the observations made by project participants.

- There are a large number of requests for additional functionality which are outside of the intended scope of the system. Boundaries or limits of the system should have been clearly defined at the outset.
- Some people are wondering what impact the system will have on their jobs, in terms of new training requirements, more computer work, etc. This concern could have implications for user acceptability, and the degree to which an institution can fully implement the system.
- FMDSS will have an impact on corporate policy and procedures. These issues should be identified as early as possible so that senior management is not surprised at a later date. Resolving these issues will be the key to successful technology transfer.
- Utilizing a structured design methodology and CASE tools is a new experience for most of those involved in project development. The time spent in learning and adopting these methods and tools has been greater than anticipated.

Conclusions

The nature and variety of forest management decisions which are amenable to decision support techniques has grown tremendously, as the underlying software technology has matured. To date, the most difficult task in developing FMDSS has been gathering and documenting knowledge about the critical aspects of the decision making process, as well as the information needs to support that process.

The software development component of the Plonski Forest Management Decision Support System Project will end in 1993. However, our understanding of the forest and the nature of decisions which we will be required to make is continuously changing. For this reason, the building of forest management decision support tools will be an ongoing process of growth and development.

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Relating Access Routes to Canada's Forest Inventory in a Geographic Information System

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Abstract

The Canadian Forest Resource Data System (CFRDS) stores information by cell, where most of the 43 000 cells correspond to provincial forest inventory map sheets. The themes include the presence or absence within each cell of access routes, including water, rail, and major or minor roads. This information was developed for the 1984 national forest biomass database, was transferred as draft quality to the 1986 national forest inventory, and is being upgraded for the 1991 inventory with the cooperation of provincial and territorial forest inventory agencies. Energy, Mines and Resources Canada has provided rail and major road network data in digital form.

The cell level access information, when combined with other CFRDS data such as the national forest inventory, can provide estimates and maps of the physical accessibility of Canada's forests. Linear networks are used to upgrade the cellular information, and can also be used for corridoring.

Concurrent Session 5

Techniques - Concepts and Issues

Data Management Issues for GISs

A Discussion of the Relative Merits of Vector and Raster Approaches to GIS

Integrating Bedrock Geology with Stream Sediment Geochemistry in a GIS: Case Study NTS 92H

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Data Management Issues for Geographic Information Systems

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Abstract

Geographic information systems deal with storage, transformation, retrieval, and analysis of spatial data. They must be capable of handling a large amount of data with complex structures and relationships. DBMS techniques are necessary to deliver the desired performance. However, a conventional DBMS cannot meet the requirements here as it is designed to handle alphanumeric data and spatial information cannot be easily extracted from such a system. Special data storage and retrieval methods have to be developed.

This paper studies spatial data features. There are four major components for spatial data: geometric, geographic, temporal, and thematic. They are distinct in nature and should be handled differently. GIS system organizations are also discussed in this paper. Especially, we focus on the design of spatial data subsystems. We demonstrate the need for both geographic access structures and the integration of different access methods to achieve optimal performance for large spatial data sets. An architecture design for spatial data subsystem is evaluated through actual implementation.

Introduction

Geographic information systems deal with storage, transformation, retrieval, and analysis of spatial data. The spatial data involved are not well formatted and have complex structures. Not only do these objects need to be stored, the relationships among them may also be stored to facilitate spatial retrieval. Geographic information systems also provide analytical tools for geographic analysis. These analytical tools distinguish a GIS from other systems, such as CAD and DBMS (Cowan, 1987). In this paper, we use the terms geographic information system and spatial data system interchangeably.

A spatial data system should provide efficient storage and retrieval for a large amount of spatial data. It is also intended for different applications by a large number of users. DBMS techniques are necessary to deliver the performance desired (Frank, 1988). However, a conventional DBMS cannot meet the requirements as it is designed to handle alphanumeric data and spatial information cannot be easily extracted from such a system. Special data storage and retrieval methods have to be developed.

This paper studies spatial data features and demonstrates the need for both geographic access structures and integration of different access methods in order to achieve optimal performance for large spatial data sets. An architecture for spatial data management subsystem is evaluated through actual implementation.

Spatial Data Model

Spatial data have four major components: geometric, geographic, temporal, and thematic. Each spatial object represents an entity in space. Its geometric part is the foundation since it describes the spatial location and shape of the object. Spatial objects are usually modeled by points, lines, and regions (or polygons). The geographic component of an object tells what the object symbolizes. Each spatial object should have a geographic meaning. For example, a line string can be used to represent a road. 'Road' here is the geographic meaning of the line string. Objects are grouped into classes according to their geographic meanings, e.g., rivers, streams, houses, etc.. A spatial object does not provide any useful information unless it belongs to a certain geographic class. An object class only allows certain object types to be geographically meaningful. For example, points may not be allowed in 'rivers' class. On the other hand, a geometric object may contribute to more than one geographic class. The same line string may serve both as a lake boundary and as a county boundary. However, this is an implementation detail and therefore should be hidden from high-level users. Temporal aspects of spatial data provide historical information as to how the objects have changed over time. An object may have different physical locations at different points in time, but they represent the same object and a logical linkage should be maintained among them so that the system would be able to answer questions like:

"Where was the city boundary for Burnaby in 1970?"

Another ability of a geographic information system is that it can associate thematic information with spatial data. A geographic information system is involved in various applications, e.g., land use, forest covers, etc., called themes. Each spatial object may participate in one or more themes and be associated with different sets of thematic data for different themes. Thematic data do not provide geometric information but give useful information for geographic analysis.

The usefulness of a spatial data system lies in its ability to extract relationships among spatial objects. Objects are related through the above discussed four attributes. Objects are related by their geometric locations, by their geographic classes, by their temporal relations, or by their thematic attributes. For instance, two objects are related because they are in the same geographic class. We have the following four types of relationships:

Geometric relations
Geographic relations
Temporal relations
Thematic relations

A spatial data system must be able to answer queries regarding these relations. Some of them may be answered by stored information whereas others may only be answered by applying a set of implemented algorithms.

This paper deals only with the geometric and geographic aspects of spatial data.

System Organizations

There are a number of approaches to implementing a geographic information system. A straightforward way would be to directly use an existing DBMS. However, with this approach it is hard to support even simple spatial operations and queries will be syntactically very complex and difficult to optimize.

A better approach is to extend a conventional DBMS by providing a user interface suitable for GIS applications. The DBMS still serves as the basic data management kernel for the GIS. Some of the early systems adopted this approach (Chang, 1980). Such a system suffers from efficiency problems due to the mismatch between the natures of conventional DBMS and spatial data.

A hybrid approach has been adopted by a number of commercial and research projects. A GIS is divided into two parts: a spatial object subsystem and a relational DBMS. The spatial component manages the storage and retrieval of spatial data while the DBMS component handles thematic attribute data. A shell suitable for GIS applications acts as the interface with the user and interacts with the two components. TERRASOFT belongs to this category.

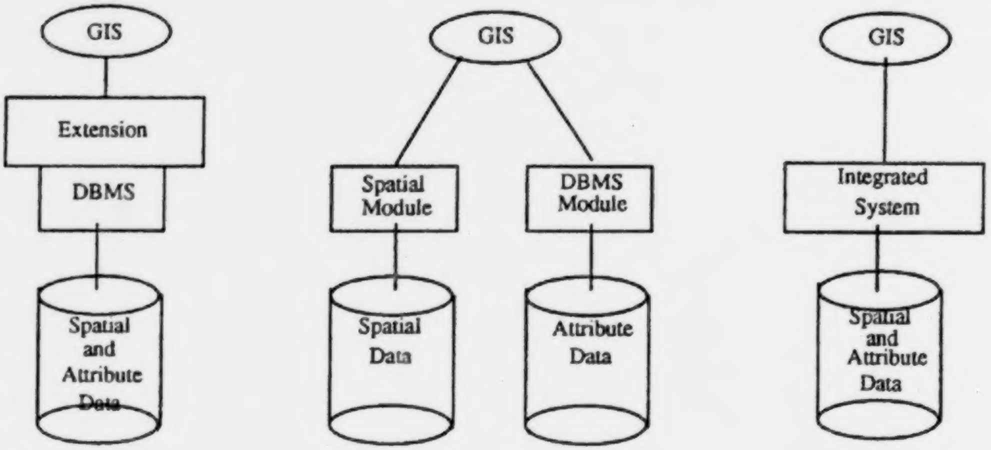
The last approach is the so-called integrated one. In this approach, a completely new system is developed from scratch that aims specially at GIS application requirements. The system is capable of handling spatial and thematic data in an integrated and uniform way. While such a system is expected to deliver the best performance, it takes considerable effort to build.

A summary of the three system organizations is shown in Figure 1. The spatial subsystem architecture proposed in the next section efficiently supports the hybrid organization and is also useful in building an integrated one

Spatial Search Operations

The need for access methods is obvious when dealing with large spatial data applications. However, no access structure is the best for extracting all kinds of spatial information. On the other hand, no spatial data system can afford the maintenance of too many access structures. Common spatial operations should first be identified in order to design access methods to best compromise performance and storage and maintenance requirements.

We are concerned with geometric and geographic relations. Accordingly, we have two types of spatial search operations: geometric and geographic operations.



Extended Approach Hybrid Approach Integrated Approach

Figure 1: System Organizations

Geometric operations concern with geometric aspect of spatial data. Objects in a spatial data system represent entities in space. The first type of geometric operations are the metrical ones which return the actual coordinates of a spatial object. They give the location and shape of a spatial object.

Spatial objects are modeled by three data types, namely, points, lines, and regions (or polygons). Therefore, there are six possible types of geometric relationships, i.e., point-point, point-line, point-region, line-line, line-region, and finally region-region relations (Nagy,1979). Topological operations are the operations regarding these relationships. A closely related and well-addressed search operation is spatial range searching. The typical form of such an operation is to retrieve all the objects within (or intersecting with) a given search range. This operation should be efficiently supported when dealing with only a small portion of the whole search space. White (1984) lists a minimum set of geometric questions which a complete spatial data system must be able to answer.

Geographic operations deal with the geographic aspect of spatial data. Class membership is the simplest geographic operation. A typical operation is to search for all objects in a specific geographic class. The region overlay operation, which is required by many geographic analysis functions, requires a similar search operation. However, this issue is not well addressed in the literature. Most of the current spatial data systems only maintain geometric access structures. Lack of geographic structures leads to inefficient searching and duplication of data.

Spatial Subsystem Architecture

Spatial objects should be effectively organized to provide an overall optimal search performance without losing the economy of data storage and the ease of manipulation. A system architecture for spatial data management is proposed in Figure 2.

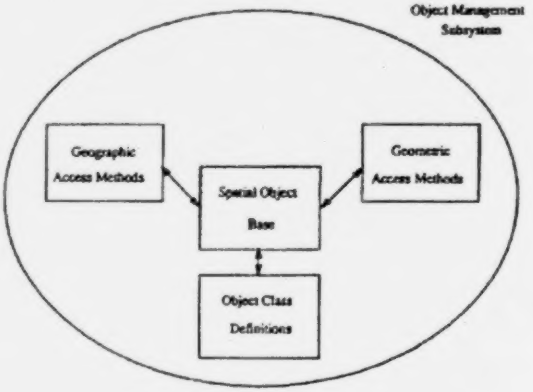


Figure 2: Spatial Data Subsystem Architecture

The architecture consists of four components: Spatial Object Base, Object Class Definition, Geometric Access Methods, and Geographic Access Methods. Spatial objects are stored in their internal form in the Spatial Object Base module. Object class information are kept separately in the Object Class Definitions module. A data path exists between them. The Geographic Access Method and Geometric Access Methods modules provide the access paths to the spatial data. All four components are integrated into one unit to form an efficient spatial management subsystem; only the interface deals with the outside world to provide optimal performance. Data storage and access details are hidden from the user. A detailed discussion is given in the following subsections.

Object and Class Manipulation

Due to the nature of spatial data, objects and their class definitions should be maintained separately to minimize data duplication and increase the flexibility of management. Objects are stored in their internal representation form in the Object Base module. Usually, they are represented by a list of coordinates. A region may be stored as a list of coordinates that represent its boundary. Each object is uniquely identified by a system-assigned identifier. Other information that is specific to the object is also kept with it.

However, information common to all objects in a class is not stored with each object. Class information is kept separately in the Class Definition. A class definition decides how the objects are stored and which operations can be applied to them. The benefits of the separation of objects and their class definitions are two-fold: minimum duplication of data and ease of data management. New objects and class definitions can easily be added and old definitions be deleted. An object can also be transferred from one class to another.

Geometric Access Methods

The need for geometric access methods is obvious. They are used to provide spatial clustering of the objects based on their spatial location.

There are a number of geometric data structures proposed to speed up range searching. Among them are R-tree (Guttman, 1984]), R+-tree (Sellis, 1987), K-D-B tree (Rob, 1981), and spatial kd-tree (Ooi, 1987). They are multi-level structures designed to handle n-dimensional objects. R-tree, R+-tree and spatial kd-tree are designed specially for non-point data. Data objects are represented by their minimum bounding rectangles. R-tree and R+-tree are n-ary trees which are the generalization of B+-trees. Each node in the tree is associated with a bounding rectangle that covers all the objects in any of its descendant nodes. The difference between the two is that the R+-tree does not allow area overlapping between sibling nodes. Duplicate data entries are introduced in exchange for efficient searching. The spatial kd-tree is binary in nature and is also designed for n-dimensional non-point data.

The K-D-B tree is suitable for point objects. There is a bounding rectangle associated with each node, which is divided into non-overlapping subregions. The subregions, when joined together, span the entire bounding rectangle. Non-point data, however, have to be mapped to higher dimensional points to make use of this structure.

The Geometric Access Methods module provides an access path to the Object Base module to facilitate geometric queries.

Geographic Access Methods

Not much effort has been devoted to geographic access methods in the literature. The need for a geographic access method for a CAD system or an image system is less obvious due to the fact they do not provide many geographic analysis functions. However, it is these analysis functions which distinguish a geographic information system from a CAD or an image system. Searching based on certain geographic feature is frequently required, especially searching based on object class. Geometric access methods are not suitable when searching is not based on spatial criteria. (Greasley, 1987) uses a lattice structure to represent geographical containment relationships. However, such a structure is not suitable for operations which involve a large amount of data. Geographic operations should first be identified and access methods can then be designed to suit the specific needs.

The Geographic Access Methods module provides an access path to the Object Base module to facilitate searching based on geographic criteria.

Integration of Different Access Methods

No general spatial data system supports only a single type of search operation. It is common that different operations need to be provided for different types of applications. Various data structures (or access methods) have been designed with a particular operation in mind. Each one performs well with the operation it is designed for. However, there are operations that are based on both geometric and geographic criteria. An example would be to search for a particular geographic feature in a small search area. In this case, which access method is the best depends on such factors as the size of the search area, the geographic feature desired, and the size of the data set. Therefore, to achieve optimal performance, different structures should be integrated into an object management subsystem which dynamically makes the decision as to which access method to use.

In the next section, we illustrate our discussion through an actual implementation.

Performance Evaluation

The spatial data management scheme discussed above has been implemented for performance study. The hardware environment consists of a number of COMPAQ 386 16-MHz machines connected by an Ethernet local area network and served by a 386 33-MHz file server. The system runs Novell NetWare as the network operating system.

Access Methods

We assume the system requirement is to efficiently support both range searches and object class searches. Range searching requires certain kind of geometric access structure, whereas a search by object class can be supported by certain geographic access methods.

Green (1989) implemented four popular geometric access methods: R-tree, R+-tree, K-D-B tree and 2D ISAM. His study shows that R-tree provides good search performance while keeping coding complexity down. Therefore, we selected the R-tree as our geometric access method. Detailed algorithms for R-tree manipulation and searching can be found in Guttman (1984).

A typical form of search by object class would be to search all the objects belonging to a geographic class regardless of their spatial location. In this situation, methods based on spatial location are no longer viable. We chose a B+-tree as our geographic access structure since it has long been demonstrated to be a good storage structure. Each object must have at least one entry in the structure since it belongs to certain geographic class(es). Each leaf entry contains a combination of a class identifier and an object identifier plus a pointer to the physical location in the Object Base module. The class identifier specifies the class the object belongs. Each non-leaf entry consists of a class identifier and an object identifier together with a pointer to a child node. The class identifier and object identifier combination serves as the access key. The B+-tree provides an overall good performance for searching, insertion, and deletion operations.

To make a comparison possible, we also implemented the sequential search method, e.g., searching without the aid of any access method.

The Data Set and Operations

Our test data map is derived from real world data which contains 16 384 spatial objects. Objects were evenly distributed across the entire map sheet. Objects were also uniformly distributed among the geographic classes, e.g., each object class contained the same number of objects as other classes.

Four types of operations were considered. The first type was to scan the entire map without any search criterion. This operation is sometimes required, as when plotting the entire map. The second operation investigated was a geographic class search where objects belonging to a specified class were retrieved. However, no geometric criterion was set and the operation is purely geographical. The third operation was range searching that retrieved objects within or intersecting with a geometric fence. Again, no geographic criterion was imposed. The last type of operation considered was the so-called mixed searching which is based on both geometric and geographic search criteria. The influence of parameters such as the total number of object classes and size of search fence was also studied. Timing was the actual elapsed time for each access method.

Results and Discussion

The first operation tested was to scan the whole map regardless of any search criteria. The test data are shown in Figure 3.

Total Number of object classes: 64
Timing is measured in seconds

Methods	Sequential	Geometric	Geographic
Timing	36.58	86.12	316.75

Figure 3: Scanning

As can be imagined, a sequential search provided the best performance in this situation since it does not have the overhead of going up and down an access structure. It simply scans the Object Base module directly. To scan the R-tree or B+-tree, the non-leaf nodes have to be accessed first. The performance depends partly on the number of entries that can be packed into each disk page.

Figure 4 shows the results for geographic class searching. For this operation, the search range was always the whole map. However, the total number of feature classes may vary, which means the number of objects belonging to each class may also vary.

Search for objects in a single class
Timing is measured in seconds

Total number of classes	Methods		
	Sequential	Geometric	Geographic
16	46.58	89.47	8.95
32	40.04	84.59	6.43
64	36.25	84.70	5.16

Figure 4: Geographic Searching

The R-tree showed the worst performance since it does not carry any object class information. It has to fetch the actual spatial objects contained in the Object Base module to check if they belong to the geographic class. Furthermore, the entire tree structure had to be searched to ensure that no object was missing, no matter what the total number of classes was. Therefore, timing did not change much as the parameter varied. The sequential search was better since, as before, it does not have tree traversal overhead. The geographic access method, B-tree, demonstrated a superior performance as expected, since objects were clustered according to their classes. The greater the total number of object classes, which implies the less the number of objects belonging to each class, the better the geographic access method was. It showed the need for a geographic access method if such a situation occured.

The third operation tested was a geometric range search which asked for all objects within or intersecting a search fence in space. Searching was based solely on geometric criteria. Here, the varying parameter was the ratio of the whole map area over the search range area. Figure 5 shows the results.

Total number of object classes: 64
Timing is measured in seconds

Whole area/ range area	Methods		
	Sequential	Geometric	Geographic
4	21.97	21.53	316.10
16	17.19	5.00	320.32
64	16.15	1.71	316.26
256	15.87	0.44	316.27

Figure 5: Geometric Searching

In this case, the geographic access method, B+-tree, gave the worst performance due to its lack of geometric information and it took about the same time regardless of the area ratio. The improvement in timing of the geometric method, R-tree, over the other methods was so much that the geometric method is indispensable for interactive applications. The smaller the search area, the better the structure. For example, when the ratio was 256, the operation was finished in less than a second.

As shown by the above discussion, no single access method was the best for all situations. Things get even more complicated when both geometric and geographic search criteria were imposed. Our last operation studied was the so-called mixed searching. It searched for objects in an object class and at the same time within or intersecting with a spatial search fence. The timing results are given in Figure 6.

Total number of object classes: 64
Timing is measured in seconds

Whole area/ range area	Methods		
	Sequential	Geometric	Geographic
4	21.14	21.54	5.16
16	17.20	5.05	5.16
64	16.32	1.75	5.22
256	15.93	0.39	5.15

Figure 6: Mixed Searching

The varying parameter here was the whole map area to search fence area ratio. The amount of time consumed by the geographic access method was almost constant as all the objects in the class have to be fetched for geometric checking. However, it still provided a reasonably good performance because only those objects belonging to the desired class have to be examined, in contrast to the sequential method which had to scan the entire file. The geometric access method was the best of the three when the search area is small.

To achieve optimal overall performance, decisions have to be made dynamically as to which access method to use, depending on the size of the data set and the search criteria. We have integrated into our spatial data subsystem the access methods and the system dynamically chooses the best access method.

Summary

We have studied spatial data attributes. There are four aspects for spatial data: geographic, geometric, temporal, and thematic. They are distinct in nature and need to be handled differently. For large data sets, both geometric and geographic access methods have to be supported to provide good performance. However, to obtain optimal performance, both access methods should be integrated into one system and method selection decisions should be made dynamically. A spatial data subsystem architecture, proposed to achieve optimal performance, is evaluated through actual implementation.

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A Discussion of the Relative Merits of Vector and Raster Approaches to GIS

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Abstract

The two traditional approaches to storing and processing GIS data are quite different. Raster and vector methods have advantages and disadvantages related in part to the way in which the GIS is intended to be used. This paper explains the two methods in some detail and goes on to discuss their relative merits.

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Integrating Bedrock Geology with Stream Sediment Geochemistry in a Geographic Information System (GIS): Case Study NTS 92H

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Abstract

An ongoing research project at the University of Victoria, conducted in conjunction with the British Columbia Geological Survey Branch, is examining alternative methodologies for computationally integrating bedrock geology with stream sediment geochemistry in a GIS, including a comparison and contrasting of different results obtained. This research note presents a cursory discussion of general methodologies for interpolating stream sediment geochemical sample points for integration with bedrock geology within a GIS. Preliminary results are discussed. Use of commercial names in this paper is for descriptive purposes only; it does not constitute endorsement by the University of Victoria or the British Columbia Geological Survey.

Introduction

Two data sets commonly used for geological resource assessment include bedrock geology and stream sediment geochemistry. Traditional methods for determining relationships between these data include both qualitative and quantitative techniques. Qualitative interpretation and integration is generally based upon visual observations of spatial coincidence between the data. Quantitative results can be derived by summarising point values according to dominant lithology of a sample's drainage area, or according to the geological unit it coincides with. Qualitative methods lack numerical explicitness, duplicability and rigour. Quantitative methods struggle with the fact that stream sediment geochemistry sample points are manipulated to represent areal distributions, where the area represented by each sample must somehow be inferred before quantitative analysis can take place. This study concerns quantitative techniques.

Geographical information systems (GIS) offer several methods for transforming geochemical points into areal coverage, allowing the resulting choropleth map to be integrated with maps depicting bedrock geology for quantitative summaries and further analyses. For example, points can be transformed into discrete homogeneous polygons (Thiessen polygons, drainage basins), or into continuous surfaces via interpolation (contouring, moving averages). This type capability obviously has tremendous potential for geological interpretation and mineral exploration.

Justification for Stream Sediment Point Transformation

For the purposes of the following discussion, the basis for transforming stream sediment point samples into areal coverages can be discussed in terms of physical factors and spatial analytical concepts. Physical factors are those which are responsible for the sediment makeup of a sample site before collection takes place. They include surficial geomorphology, bedrock geology, structure, atmospheric pollutants, fauna, flora and other physiographical variables. Spatial concepts entail upstream analysis, spatial autocorrelation, proximity, and distance decay. There also exist other non-physical factors, including sampling and recording techniques, and analytical procedures, which may contribute to error and uncertainty of geochemical determinations, but these do not constitute a basis for spatial transformation. These latter non-physical factors are beyond the control of this study and will not be considered further.

1. Physical Factors

The catchment basin associated with a given stream sediment sample is the dominant physical factor controlling the input of material. It can be determined by including successively adjacent locations with elevations higher than the point of sampling. Within a basin, various other physical factors may influence the stream sediment sample composition, or contribute to within-basin variation. These include slope, aspect, curvature, vegetation, differential weathering of geology, rainfall and wildlife. There are also factors which transcend drainage basin boundaries. Geological material from beyond the catchment boundary may be present due to glacial transportation and atmospheric pollutants; it is also possible for ground water flow and biological activity to transport material across watershed boundaries.

2. Spatial Analysis

The 'first law of geography' states "...everything is related to everything else, but near things are more related than distant things." (Tobler, 1970:236). In map variables exhibiting spatial pattern due to proximity, spatial autocorrelation is said to exist (Johnston, 1986). Assuming spatial autocorrelation exists, how does it affect the nature of spatial patterns? Spatial autocorrelation is associated with the topological relationships and metric relationships between spatial phenomena. Spatial patterns can therefore be discerned, based upon topological and metric analysis, including directional relationships (upstream vs downstream), adjacency, proximity and through metric distance decay. The role of stochastic processes, of course, should not be ignored. Given the above, a number of techniques have been developed to translate point data into areal coverage based upon the concept of spatial autocorrelation.

Techniques for Transforming Point Data

Techniques for transforming point data into thematic maps can be divided into discrete and continuous methods. Discrete methods assume that a distinct area can be associated with each point, and that there exists no variation within this area; variation occurs abruptly along polygon boundaries only. In contrast, continuous methods assume that variation is gradual between observation points or over the entire area of interest. A number of transformations are briefly introduced below. Most commercial GIS support one or a number these techniques. The reader is referred to Burrough (1987), George and Bonham-Carter (1990), McCullagh (1988), Davis (1986) or Lam (1983) for in-depth discussions.

1. Catchment Basins

Catchment basins have been used to define area of influence polygons for stream sediment samples (Bonham-Carter et al., 1988; Dwyer and Nash, 1987; Rogers et al., 1990). Catchment basins assume elevation to be the defining criteria for a sample point area of influence. This is a discrete polygon method and therefore assumes within-polygon uniformity of geochemistry. Catchment basins can be determined manually from elevation contours, a time-consuming and tedious task, or digitally from a digital terrain model. Not all GIS support automatic digital watershed identification routines.

2. Thiessen Polygons

Thiessen polygons, also known as Voronoi or proximal polygons, assume that the extent of a point's influence can be strictly defined by its proximity to neighbouring points. Thus for a given distribution of points, Thiessen polygons are defined by joining perpendicular bisectors of lines connecting all neighbouring points. All locations in resulting polygons are closer to the defining point than any other (assuming an unweighted transformation). Thiessen polygons are a discrete method and the primary drawback again is their inability to reflect within polygon variation and gradual changes between sample points (Saxton, 1989). For a detailed discussion of Thiessen tessellations, see Gold (1989) or Burrough (1987).

3. Contouring

This method is analogous to the manual contouring approaches traditionally employed by geologists. A continuous surface can be created by determining the values at unknown locations through linear interpolation between known values. This method assumes sample points represent exact locational values, and the method may not be appropriate if critical values (local maxima or minima) are not defined by the point distribution. Interpolation between sample points can be both linear or non-linear.

4. Weighted Averages

This represents a local interpolation method which considers the values of several points within a defined window (or kernel) to determine an average value for any point within it. Averaging can be linear or non-linear by defining appropriate distance decay parameters. The method is discussed in detail by Burrough (1987) and George and Bonham-Carter (1990). A number of limitations have been identified. Problems may occur if the data points tend to be clustered (Burrough, 1987), and the original data values may be lost due to generalisation. The user is also required to have some knowledge of the data which allows for the determination of appropriate kernel size and distance decay parameters.

5. Optimal Interpolation

Optimal interpolation, or Kriging, assumes that variation is too complex to be modelled using mathematics, and that it therefore must be treated as a stochastic process. The technique depends upon the variogram for summarising the form of the variation, its magnitude, and spatial scale (Oliver and Webster, 1990). Original data values are maintained and estimates of error can be obtained (Burrough, 1987). This type of optimal interpolation procedure largely is absent in commercial GIS software. However Oliver and Webster (1990) believe it can be incorporated.

6. Trend Surface Analysis

Trend surface analysis is a global interpolation technique; values for a given location are determined by considering the entire data set. The methods listed above are local interpolators. This method employs multiple regression to determine a polynomial equation which can be used to estimate the value for any given location. This method is susceptible to highly anomalous values (Burrough, 1987) and original data values are not represented in the resulting surfaces.

7. Classifying Continuous Surfaces

Point data transformed into continuous surfaces can be made discrete through classification methods. This may be useful for display purposes but results in generalisation and loss of resolution if used for analysis. Classifying continuous data also requires an appropriate scheme for grouping data values based upon some underlying nature (e.g., statistical). See Burrough (1987) for a discussion of techniques and problems associated with classifying continuous data.

Integrating Stream Sediment Geochemistry with Geology in a GIS

The practical aspects of data input, transformation and integration of the two geoscience data sets are described in this section. The study area used is as defined by the boundary of NTS 92H, located in the southeastern region of the province of British Columbia.

1. Data Input

A 1:250 000 scale bedrock geology map (NTS 92H, Monger, 1989) containing 791 polygons was manually digitised. Attribute tags identifying map units were added to each polygon. Including water bodies, there are 62 classes; a generalised description of each class is provided in Table 1. Catchment basins were manually determined from elevation contours (NTS 92H) according to the location of stream sediment sample points (BC-RGS-7). Of the 995 sample locations for 92H, 55 are duplicate samples and another 27 lack elemental analyses; these sample locations were discarded. Of the remaining 913, two fell on the southern map sheet boundary and appreciable catchment basins could not be determined. 911 stream sediment catchment polygons thus were determined and digitised. Each polygon on the catchment map is treated as a unique class unto itself, and geochemical records in ASCII format were attached to corresponding catchment polygon tags. Both maps were digitised in an arc-node vector format using PC-ARC/INFO software. Upon completion of input, both polygonal data sets were formatted into an ASCII file and re-input to TYDAC SPANS GIS for further processing. The original geochemistry point file (913 points including the two points along the southern boundary) was input to SPANS as a third primary data set.

2. Data Transformation

In the SPANS GIS environment, both polygonal maps were rasterised to a resolution such that the accuracy of the digitised boundaries were not compromised (final resolution exceeds 100 metres on the ground). Using the coverage of the catchment basins as a binary template (coverage present, coverage absent), a second geology map was 'cut out' such that the resulting area matched exactly with the catchment coverage. A Thiessen polygon map, totalling 913 separate polygons, was generated from geochemical point locations, and geochemical determinations were assigned as attributes to each polygon. A summary of each map variable is provided in Table 2.

3. Data Integration

Treating the geology and 'cut-out' geology maps as dependent variables and the Thiessen and catchment maps as corresponding independent variables, each map-pair was overlaid to determine average elemental concentrations for each geology class, weighted by area. Overlay of map-pairs were performed ten times using as attributes for the independent maps the following elements: zinc, copper, lead, nickel, cobalt, silver, manganese, iron, molybdenum and tungsten. A point-in-polygon overlay was performed using the geochemical point data set as the dependent variable and the geology map as the independent variable, such that the geology classes were appended to spatially coincident points. Subsequent processing on the updated point file using dBASE III+ allowed each geology class to be summarised according to the average concentration for each of the ten elements listed above.

The raw results from each overlay set are summarised in Table 3. The results for the polygon overlay sets are average values weighted by area; the point-in-polygon overlay is averaged by the number of contained points in each geology class. Totals for the entire map are included. The Thiessen map covered the entire map area; therefore, all geology classes contain summaries for this overlay set. The catchment map covered only those areas defined by catchment basins; therefore, three geology units were missed and could not be summarised. The potential for missing is even greater for the point-in-polygon overlay as it is dependent upon point-area intersections; ten units lack summaries from this overlay.

Included in Table 3 are summaries of the total area and point intersections for each geology map unit as well as total map areas. From this information it can be determined that stream sediment catchment basins cover 57.7% of the map area.

	QUATERNARY
1	Drift; alluvium; colluvium, recent deposits.
2	Basaltic flows.
	TERTIARY
3	Basalt, olivine basalt, minor flows.
4	Intermediate, felsic pyroclastics and flows.
5	Granodiorite
6	Intermediate, felsic pyroclastics and flows.
7	Granodiorite
8	Granodiorite
9	Intermediate with local mafic and felsic flows, volcaniclastics.
10	Sandstone, conglomerate, argillite.
11	Granodioritic and intermediate intrusions.
	CRETACEOUS AND/OR TERTIARY
12	Pegmatitic granite gneiss; pelitic schist, amphibolite, minor marble, ultramafic rocks.
13	Blue schist, local amphibolite, minor marble and ultramafic rock.
14	Greenschist: mafic to intermediate volcanics, phyllite, minor volcanic, conglomerate.
	CRETACEOUS
15	Granodiorite, quartz monzonite.
16	Mainly granite.
17	Felsic intrusions.
18	Intermediate, locally felsic, mafic volcanics sandstone, shale, conglomerate.
19	Mafic volcanics.
20	Chert-grain sandstone and conglomerate.
21	Undifferentiated sediments.
22	Sandstone, argillite, conglomerate.
23	Intermediate intrusions, minor ultramafic rock.
24	Felsic and mafic gneiss.
	JURASSIC(?) AND CRETACEOUS
25	Intermediate pyroclastics and flows.
26	Sandstone, conglomerate.
27	Granodiorite and gneiss.
28	Diorite and amphibolite.
29	Granite and pegmatite.
30	Sandstone, conglomerate, argillite.
31	Conglomerate, sandstone, argillite.
32	Granite and Granodiorite.
33	Intermediate volcaniclastics.
34	Argillite, tuff.
35	Intermediate, locally felsic flows and pyroclastics; local argillite, conglomerate.
36	Argillite, slate, siltstone, tuff.
37	Sandstone, argillite; local mafic, intermediate volcanics.
	TRIASSIC AND/OR JURASSIC
38	Granodiorite.
39	Diorite, amphibolite.
40	Syenite, diorite, gabbro, ultramafic rock.
41	Argillite, sandstone, minor carbonate.
42	Mafic to felsic volcanics, minor argillite.
43	Felsic to intermediate pyroclastics, argillite
44	ntermediate pyroclastics and flows.
45	Mafic pyroclastics and flows.
46	Argillite, sandstone, tuff, breccia, conglomerate
47	Amphibolite, diorite, mylonite, schist, marble.
48	Siliceous argillite, mafic volcanics.
49	Mafic volcanics.
50	Granite-gneiss.
51	Carbonate.
52	Schist, meta-chert, pelite, amphibolite, marble, ultramafic rock.
53	Ultramafic rock, local gabbro.
	PERMIAN TO JURASSIC
54	Chert, pelite, mafic volcanics, minor limestone, gabbro and ultramafic rock.
55	Mafic volcanics.
56	Siliceous and chlorite schist, phyllite.
57	Ultramafic rock and local gabbro.
	ORDOVICIAN TO TRIASSIC
58	Argillite, chert, mafic volcanics, minor carbonate and ultramafic rock.
59	Amphibolite, gneiss, minor ultramafic rock.
	DEVONIAN TO PERMIAN
60	Pelite, sandstone, minor conglomerate, mafic and felsic volcanics; carbonate.
61	Metadiorite and gabbro.
70	Water bodies

Table 1: Description of geological units, generalised after Monger, 1989.

4. Edge Problems

Geoscience data sets tend to be collected and distributed according to NTS map boundaries. Such boundaries impose limitations, or edge effects, when used as a basis for data integration. Catchment basins of stream sediment samples are either cut off or not included, depending upon which side of the boundary they fall on. Points immediately adjacent to the map area will also change Thiessen polygon configurations and affect the transformation of geochemical points into continuously varying surfaces through contouring, Kriging and weighted averages. The point-in-polygon method appears to be the only one that is unaffected by edge effects.

Data Variable	Data Type	Attributes	Input/Source
Stream Sediment Geochemistry	Points	Geochemical Elements	Digital files; GSC OF 865_ /MEMPR BC RGS 7
Drainage Basins as criteria	Polygonal	Geochemical Elements	Digitised; derived from NTS 92H using geochemical points
Bedrock Geology	Polygonal	Geological Classes	Digitised from 1:250 000 GSC geology map 92H
Geology Cut To Drainage Cover	Polygonal	Geological Classes	Derived from intersection of Geology/Drainage Maps
Thiessen Polygons	Polygonal	Geochemical Elements	Computed from geochemical point locations

Table 2: Summary of data variables used for the study.

Summary and Prospects

Geological interpretation and explanation of the data is not attempted here since this research note focuses upon the application of various techniques for transforming geochemical point data for subsequent integration with geology. However, a visual examination reveals obvious correlations between the three techniques. Further interpretation is left up to the reader at present, but will be reported in a future paper.

Although there is a conceptual basis for both Thiessen and catchment basin transformations, the latter is intuitively more appealing. Catchment basins account for a primary physical factor controlling the spatial influence of stream sediment sample points. Strict proximity of Thiessen polygons is a more abstract concept based upon the assumption that spatial autocorrelation exists. In regions of high relief, where catchment basins are easily defined, it is difficult to understand how Thiessen polygons can offer any advantage. However as relief becomes flat and drainage boundaries are not as easily defined, then proximity may offer some advantages. Both methods do not allow for within-polygon variation. If variation is perceived as being important, then techniques for interpolating points into continuous surfaces will be more appropriate.

In applying these techniques, basic questions regarding the nature of geochemical point samples are put forth. Do the samples represent point or areal coverage? Are the distributions discrete or continuous, stochastic or deterministic? What physical and spatial factors determine a sample's area of influence? It is therefore important that the assumptions and limitations of the various methods are understood. Ongoing work includes expanding the study to include additional interpolation techniques and a study of the impact of edge problems on overlay results. Future research will include a quantitative comparison and explanation of the results each interpolation method produces through overlaying with geology.

The techniques presented here offer considerable potential to assist with geological research and mineral exploration. However, digital spatial integration of geological data sets is currently not widely practised. The barriers for doing so can be identified as expensive technologies and a lack of digital map data bases (geology, topography). Price-performance ratios for computer hardware and software are doubling every one to two years, and provincial coverage of geochemistry and terrain data in digital formats will soon be complete. Development of digital geological map data bases by the appropriate authorities must also take place. Such databases should include seamless concepts (geographical elements are logically connected across NTS boundaries) such that users are not restricted to analysis by NTS map sheets, but can choose regions more appropriate to the task, such as major watersheds or geological terranes. The development and adoption of map data base standards by various government agencies would also be helpful.

Unit	Area Sq. km.		Pts	Zinc (ppm)			Copper (ppm)			Lead (ppm)			Nickel (ppm)		
	B	T	PiP	B	T	PiP	B	T	PiP	B	T	PiP	B	T	PiP
1	964.6	2091.6	206	60.8	72.4	75.4	30.5	31.4	34.9	4.53	5.98	5.7	18.4	18.2	18.0
2	5.2	6.9	0	50.8	53.2	21.6	23.7	1.86	2.44	8.6	6.9				
3	8.4	1.8	0	57.7	64.4	16.2	20.8	3.82	6.30	7.3	13.8				
4	9.1	9.1	1	123.4	61.4	56.0	53.5	36.4	33.0	16.81	12.07	12.0	36.7	11.4	10.0
5	151.1	206.0	12	39.7	40.9	30.9	22.1	21.8	21.2	4.87	6.20	5.2	15.0	11.6	9.1
6	53.7	70.1	2	72.2	68.3	79.5	18.8	19.7	16.0	11.59	10.10	19.5	18.6	8.8	9.5
7	170.2	312.7	24	62.9	50.8	57.0	32.2	30.2	32.8	10.25	6.80	7.5	19.0	12.9	12.5
8	209.2	240.7	10	60.9	52.1	44.7	15.5	14.4	9.0	4.04	4.45	3.9	11.3	12.8	4.0
9	271.3	429.7	15	54.6	52.1	51.0	30.0	27.4	32.3	5.92	5.35	6.3	13.4	13.8	12.1
10	63.9	167.6	12	52.7	60.7	55.0	24.7	28.9	20.5	6.04	6.80	5.1	17.8	14.3	11.4
11	96.2	182.0	9	68.9	68.7	88.2	30.4	29.4	28.2	4.81	5.26	9.4	31.8	29.1	17.4
12	111.7	218.4	22	68.7	62.5	63.4	33.4	30.5	33.0	6.29	3.80	3.3	36.4	52.3	63.9
13	210.9	344.4	22	50.8	49.8	48.9	35.6	32.0	36.3	2.96	2.90	2.5	43.9	37.2	39.7
14	13.2	17.1	0	126.6	104.8	53.3	47.8		6.96	6.22		61.0	52.8		
15	495.4	705.3	32	43.6	36.9	34.7	8.7	4.7	3.2	3.09	3.27	3.0	8.9	7.0	5.9
16	315.6	377.5	13	93.5	83.9	49.3	41.8	33.0	15.8	10.77	9.07	5.8	5.8	5.1	5.7
17	45.0	93.9	6	125.5	172.1	84.7	90.8	96.5	48.2	14.14	19.58	11.7	7.8	10.3	8.0
18	401.2	696.8	41	61.6	63.5	62.9	18.9	20.5	20.2	4.15	4.48	3.8	9.3	9.4	9.4
19	115.5	264.0	17	58.5	64.2	62.5	32.1	37.4	39.1	2.81	3.22	3.8	51.2	38.4	25.2
20	12.0	13.0	1	70.2	70.1	73.0	29.7	38.7	29.0	4.50	3.97	1.0	8.3	10.2	8.0
21	346.0	478.3	21	80.7	62.3	63.0	20.3	21.3	20.0	4.48	6.58	8.0	14.3	14.4	12.0
22	165.1	294.5	22	102.2	102.2	102.7	31.0	38.4	54.5	6.20	7.52	9.0	21.4	18.8	17.8
23	455.0	816.2	52	39.8	42.6	43.6	22.0	21.7	20.0	2.97	3.56	3.7	26.1	24.5	24.0
24	29.7	71.0	2	32.6	37.4	34.5	32.6	30.4	18.0	4.43	4.80	3.0	3.7	4.7	8.0
25	50.6	87.5	7	63.2	70.1	69.4	31.7	31.4	34.1	3.84	4.81	5.9	9.0	9.8	9.6
26	5.8	61.3	2	73.7	89.3	105.0	26.3	37.5	48.0	3.11	3.05	2.5	10.8	26.6	35.0
27	370.5	611.4	38	46.6	50.5	50.9	16.5	17.2	16.3	3.14	3.81	4.1	7.0	7.0	8.5
28	15.6	46.7	2	58.6	66.0	57.0	29.4	23.6	20.0	6.18	9.30	9.0	14.8	14.9	30.0
29	125.4	161.9	8	54.7	53.0	51.2	22.3	17.6	15.2	4.32	5.01	5.6	10.3	7.9	6.9
30	6.0	10.3	0	130.2	201.8		58.9	91.9		9.64	16.64		20.8	26.7	
31		15.6	0		154.7			31.9			15.04			10.2	
32	660.6	993.4	33	58.6	64.1	86.3	12.3	13.6	13.7	5.50	5.41	7.8	4.1	4.1	4.2
33	6.0	9.4	1	79.6	84.5	70.0	23.9	22.9	20.0	4.89	6.45	4.0	7.4	7.0	6.0
34	12.4	13.7	2	85.0	92.8	95.0	23.4	23.9	24.0	8.21	9.62	9.0	6.4	6.2	6.5
35	127.1	258.7	13	192.3	131.6	111.5	30.0	30.9	31.2	12.08	9.56	7.9	5.3	5.5	4.8
36	219.8	281.2	15	128.5	142.1	97.7	35.5	59.5	26.9	17.87	22.49	5.5	43.4	35.9	36.8
37	227.2	331.1	19	109.1	97.3	90.1	24.1	24.1	21.8	6.60	6.35	5.0	16.7	14.8	11.6
38	533.3	1117.7	51	54.6	54.0	54.5	17.3	20.4	20.3	3.79	3.96	3.6	7.8	7.1	7.0
39	136.6	161.6	5	42.4	41.1	42.4	27.1	29.3	29.6	1.74	1.91	2.4	12.7	8.7	9.6
40	63.5	104.0	4	64.1	58.7	54.2	59.6	77.2	115.8	3.30	4.06	3.0	27.1	38.4	44.8
41	44.3	166.7	9	127.7	117.6	122.8	46.2	45.0	48.1	4.78	5.02	5.1	25.6	27.8	31.2
42	210.5	338.0	17	71.2	71.1	65.4	33.9	35.7	34.8	4.25	3.87	3.4	14.7	18.0	18.1
43	63.8	88.7	7	70.0	70.5	70.7	33.8	38.4	37.7	1.36	1.83	1.6	9.6	10.2	10.3
44	165.9	190.4	6	72.4	65.5	61.7	30.6	37.3	37.0	3.89	4.93	3.0	6.0	9.2	6.5
45	440.1	715.0	32	65.0	65.2	71.9	48.1	58.5	66.5	4.10	3.94	4.3	10.3	10.4	10.7
46	220.0	324.3	10	52.2	52.2	50.8	17.0	19.2	22.4	2.40	2.77	2.9	6.9	8.5	10.5
47	91.6	237.8	10	61.4	59.9	56.6	39.5	32.1	37.5	3.56	4.21	3.2	15.6	13.1	10.3
		1.6	0		73.0			31.3			4.00			4.3	
49	4.2	6.3	0	68.5	71.8		27.2	25.7		3.05	5.02		98.4	103.0	
50	25.9	25.9	2	38.7	34.8	34.0	23.5	19.1	13.5	2.74	3.00	4.5	15.0	13.3	8.0
51	0.8	0.9	0	38.0	34.7		22.0	25.0		2.00	1.67		18.0	6.7	
52	49.3	71.3	5	43.1	46.8	47.6	28.4	32.6	43.2	2.93	3.23	2.0	47.2	48.0	30.0
53	28.7	40.2	2	69.5	70.3	65.5	31.9	31.3	23.0	3.48	4.75	3.5	165.6	174.0	
54	368.8	592.9	32	104.5	109.8	121.0	55.8	56.6	58.1	10.18	11.62	25.9	62.3	71.2	59.5
55	130.0	225.7	19	144.7	161.0	135.9	96.0	101.7	97.2	9.87	22.32	10.3	57.8	57.9	58.7
56	1.3	18.4	4	57.9	68.5	64.8	24.8	36.6	31.0	1.31	1.14	1.2	21.5	31.5	24.2
57	2.3	5.1	1	83.4	88.7	94.0	44.5	43.6	40.0	4.06	4.34	7.0	124.6	89.0	96.0
58	37.3	97.0	7	52.0	51.3	55.4	22.5	22.6	28.3	3.53	2.92	3.1	13.2	13.2	19.1
59		8.1	0		106.0			29.0			5.00			11.0	
60	74.9	219.9	8	98.0	101.5	111.5	38.7	39.9	44.0	5.18	5.51	5.8	27.8	24.0	21.8
61	8.8	21.1	0	58.1	60.9		37.4	33.9		4.47	4.54		55.0	60.2	
70	10.0	260.6	0	38.5	99.8		26.0	38.9		5.49	5.08		4.9	17.4	
Tot.	9261.3	16060.3	913	67.7	69.5	69.7	28.4	30.5	31.9	5.42	5.81	5.9	18.2	18.0	19.5

Note: B - Drainage basin; T - Thiessen polygon; PiP - Point-in-Polygon

Table 3: Overlay summaries.

Uni	Cobalt (ppm)			Silver (ppm)			Manganese (ppm)			Iron (%)			Moly. (ppm)			Tungsten (ppm)		
	B	T	P/P	B	T	P/P	B	T	P/P	B	T	P/P	B	T	P/P	B	T	P/P
1	8.4	8.4	8.3	0.12	0.14	0.13	467.1	527.5	461.4	1.93	2.14	2.04	1.3	1.5	1.7	1.2	1.2	1.3
2	7.0	7.1		0.10	0.10		476.7	536.8		1.87	1.87		2.1	1.8		1.0	1.0	
3	7.0	8.3		0.10	0.19		438.1	670.9		2.28	2.45		1.1	1.3		1.0	1.2	
4	16.6	9.8	9.0	0.18	0.10	0.10	811.8	308.4	275.0	3.78	2.58	2.50	2.8	1.9	2.0	1.3	1.0	1.0
5	6.2	5.6	5.4	0.10	0.11	0.10	195.0	214.2	173.0	1.75	1.81	1.49	1.5	1.5	1.4	2.3	2.2	2.2
6	7.0	7.1	7.0	0.22	0.11	0.10	483.8	559.2	810.0	1.66	1.88	1.83	1.2	1.4	2.0	1.0	1.0	1.0
7	7.4	8.4	6.6	0.18	0.13	0.11	325.5	308.7	464.0	1.91	1.78	1.74	1.7	1.3	1.5	2.1	3.6	4.8
8	6.3	6.1	5.1	0.10	0.16	0.10	282.1	270.1	251.2	2.05	2.11	1.38	1.8	1.7	2.4	2.5	1.9	1.0
9	6.4	6.6	6.1	0.13	0.11	0.11	438.8	457.9	298.1	1.69	1.66	1.59	1.3	1.1	1.1	1.0	1.1	1.0
10	7.0	7.6	7.3	0.11	0.12	0.10	361.6	446.1	481.3	1.70	1.82	1.74	1.1	1.2	1.1	1.2	1.2	1.2
11	10.1	9.4	8.3	0.12	0.13	0.16	353.4	373.6	455.1	2.28	2.15	2.21	1.4	1.5	1.7	1.0	1.0	1.1
12	8.2	9.6	10.8	0.12	0.11	0.11	300.4	303.9	310.9	2.11	2.14	2.27	1.7	1.3	1.3	2.3	1.0	1.0
13	8.5	8.6	6.9	0.11	0.11	0.10	197.3	194.6	175.6	1.73	1.70	1.75	1.6	1.5	1.4	3.8	2.7	1.3
14	17.2	14.9		0.10	0.10		619.4	504.0		4.32	3.72		3.0	2.5		1.0	1.0	
15	3.3	2.4	2.1	0.10	0.10	0.10	187.6	135.1	131.7	0.92	0.71	0.67	1.1	1.1	1.1	1.1	1.1	0.9
16	3.7	4.0	3.7	0.16	0.14	0.15	505.7	618.7	667.1	1.44	1.48	1.43	1.8	2.1	2.0	1.3	1.6	1.5
17	5.3	5.9	5.2	0.37	0.37	0.23	650.9	666.7	514.7	2.28	2.19	2.13	2.7	2.4	1.8	1.1	1.1	1.0
18	7.3	7.6	7.8	0.12	0.13	0.11	568.2	646.3	670.1	2.11	2.15	2.16	1.3	1.5	1.4	1.0	1.0	1.1
19	9.1	10.2	9.5	0.10	0.11	0.11	260.7	258.3	245.0	1.91	2.09	2.07	1.2	1.3	1.4	3.1	2.7	1.9
20	7.5	8.1	8.0	0.10	0.10	0.10	744.2	687.7	680.0	2.00	2.10	2.10	1.0	1.0	1.0	1.0	1.0	1.0
21	7.8	7.5	6.6	0.21	0.27	0.15	427.8	434.5	368.4	2.01	1.91	1.72	1.2	1.2	1.4	1.0	1.0	1.0
22	12.0	12.0	13.3	0.15	0.18	0.23	590.7	623.8	592.0	2.95	2.87	3.02	1.7	1.5	1.7	1.0	1.4	2.1
23	6.3	6.8	6.5	0.11	0.10	0.11	170.6	193.7	129.9	1.32	1.38	1.34	1.2	1.4	1.3	1.7	1.8	1.0
24	4.9	5.6	5.5	0.12	0.12	0.15	153.8	161.8	130.0	1.26	1.30	1.02	1.9	1.8	1.5	8.3	7.4	13.0
25	13.1	13.7	13.8	0.11	0.11	0.13	513.9	582.3	543.1	3.07	3.25	3.09	1.1	1.0	1.1	1.0	1.0	1.0
26	11.2	12.0	13.5	0.16	0.11	0.10	540.0	412.9	338.0	3.14	3.14	3.23	1.7	1.1	1.0	1.0	1.0	1.0
27	5.1	6.0	6.1	0.11	0.11	0.11	375.4	451.8	450.9	1.52	1.68	1.71	1.4	1.3	1.1	0.9	1.0	1.0
28	8.1	7.7	8.5	0.10	0.17	0.10	422.8	481.6	370.0	1.72	1.78	1.70	1.1	1.8	1.0	1.0	1.0	1.0
29	6.8	5.7	4.5	0.10	0.11	0.12	370.2	416.8	405.4	1.60	1.43	1.22	1.4	1.2	1.1	1.5	1.0	1.0
30	13.0	16.7		0.25	0.46		693.5	826.4		3.30	3.93		2.0	3.4		2.2	3.8	
31		8.9			0.21			1136.9			2.97			1.8			1.0	
32	4.1	4.1	4.6	0.11	0.12	0.14	639.6	589.9	744.0	1.73	1.61	1.74	1.5	1.7	1.5	1.1	1.5	1.5
33	12.7	12.6	9.0	0.14	0.11	0.10	728.0	792.1	467.0	3.63	3.78	3.00	1.4	1.1	1.0	1.0	1.0	1.0
34	11.4	12.7	14.0	0.16	0.16	0.15	745.6	898.0	990.0	3.36	3.77	4.15	1.6	1.6	1.5	1.0	1.0	1.0
35	10.4	9.1	8.7	0.19	0.14	0.12	1120.8	768.5	545.4	3.18	3.10	3.10	2.3	2.3	2.6	1.0	0.9	1.0
36	12.8	12.9	10.5	0.37	0.53	0.11	542.4	565.8	450.5	3.14	3.04	2.65	2.1	2.4	1.7	1.1	2.4	1.9
37	9.6	9.6	8.8	0.31	0.15	0.25	532.2	518.6	474.4	2.59	2.47	2.20	1.4	1.4	1.3	1.2	1.0	1.0
38	5.9	5.6	5.8	0.14	0.13	0.13	565.6	563.8	562.0	1.93	1.95	1.94	1.4	1.6	1.4	1.3	1.3	1.7
39	9.8	8.0	9.6	0.10	0.10	0.10	359.6	314.8	401.2	1.75	1.85	2.00	1.1	1.2	1.2	1.1	1.0	1.0
40	14.8	13.8	13.8	0.15	0.11	0.12	612.2	674.3	1113.8	2.79	2.53	2.45	1.2	1.0	1.0	1.0	1.0	1.0
41	13.3	13.0	13.6	0.18	0.16	0.17	843.2	758.4	852.7	3.80	3.81	3.70	2.4	2.0	1.6	1.0	1.0	1.0
42	11.1	11.7	11.7	0.20	0.13	0.15	502.0	567.5	600.6	2.53	2.49	2.47	1.3	1.3	1.4	1.0	1.1	1.1
43	9.3	9.7	9.4	0.10	0.10	0.10	2581.6	1127.4	1602.9	2.45	2.51	2.46	1.6	1.4	1.4	1.1	1.1	1.0
44	6.4	7.5	7.7	0.10	0.10	0.10	664.9	530.4	489.5	1.93	1.93	1.88	1.1	1.2	1.2	1.0	1.0	1.0
45	7.6	7.8	8.4	0.12	0.12	0.12	690.0	792.4	791.5	1.99	2.18	2.57	1.6	1.5	1.6	1.0	1.1	1.1
46	4.8	4.9	5.2	0.13	0.13	0.12	464.1	516.2	691.7	1.39	1.53	1.83	1.6	2.0	1.6	1.2	1.0	1.0
47	11.2	8.8	7.7	0.24	0.12	0.11	501.8	443.8	383.4	2.44	2.11	1.99	1.5	1.5	1.9	1.1	1.1	1.1
48		7.8			0.10			370.0			3.05			3.5			1.0	
49	13.8	14.3		0.10	0.11		413.9	432.3		2.70	2.75		1.3	1.5		1.0	1.0	
50	6.8	5.8	5.0	0.10	0.10	0.10	136.5	152.2	136.0	1.19	1.09	1.00	2.1	2.2	3.0	16.4	10.4	20.5
51	10.0	7.3		0.10	0.10		265.0	200.0		1.55	1.32		1.0	1.0		1.0	1.0	
52	8.9	9.3	10.4	0.10	0.10	0.10	159.1	174.7	175.6	1.35	1.46	1.52	1.3	1.2	1.0	5.5	1.7	1.0
53	17.7	18.2	26.0	0.11	0.13	0.10	395.6	399.7	470.0	2.83	2.58	2.95	1.2	1.2	1.0	1.1	1.1	1.0
54	17.5	18.5	18.7	0.17	0.20	0.51	613.1	637.5	675.8	3.51	3.48	3.66	2.3	2.4	2.4	1.6	1.4	1.2
55	26.9	27.3	26.1	0.16	0.38	0.18	748.3	754.3	733.4	4.28	4.11	3.91	3.2	3.7	3.8	1.5	1.9	2.2
56	9.9	12.1	11.0	0.10	0.10	0.10	234.7	237.4	218.0	1.86	2.26	2.11	1.0	1.3	1.0	1.0	1.0	1.0
57	20.0	17.1	20.0	0.10	0.10	0.10	519.8	461.2	435.0	3.34	3.01	3.80	2.1	2.1	2.0	1.0	1.0	1.0
58	7.0	6.7	8.4	0.12	0.14	0.14	383.6	368.2	360.6	1.96	1.83	1.94	1.3	1.3	1.3	2.5	2.5	1.8
59		9.0			0.20			2400.0			2.75			3.0			1.0	
60	11.5	11.5	12.0	0.15	0.18	0.21	483.9	515.3	507.9	3.30	3.34	3.62	2.2	2.0	2.0	1.0	1.1	1.0
61	11.6	11.2		0.11	0.11		275.4	271.6		2.13	2.00		1.7	1.4		1.0	1.0	
70	4.7	11.4		0.10	0.12		205.4	589.0		1.41	2.80		1.2	1.4		5.2	2.2	
Tot	8.0	8.2	8.5	0.14	0.14	0.14	482.8	495.7	483.3	2.02	2.07	2.09	1.5	1.6	1.6	1.4	1.4	1.4

Note: B - Drainage Basin; T - Thiessen Polygon; P/P - Point-in-Polygon.

Table 3: Continued.

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Concurrent Session 6

Legal Issues and GIS

A Sketch of Legal Issues Confronting Government GIS

A Corporate Perspective for Treating Data as an Asset

Some Major Legal Issues Affecting the Canadian GIS Model and its Participants

GIS'91
Symposium

Vancouver
British
Columbia
February 1991

A Sketch of Legal Issues Confronting Government GIS

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Abstract

Laws, particularly those associated with public records and copyright, have not kept abreast of technology. The implications on the developers and consumers of products and services for geographic information management systems are diverse. Furthermore, they are important to the financial security of the GIS and the custodian organization. This paper sketches some of the key concerns that managers and developers of GIS will need to address. The paper also provides guidance to the more comprehensive discussions of the emerging issues.

Introduction

Access and dissemination of the products and services of geographic information systems present policy, procedural, and legal issues for both producer and consumer. From both the perspective of public and private entities, the current legal setting of federal, sta te or provincial, and local jurisdictions affects the implementation.

In part, constraints impacting the realization of the potential value gained from the dissemination of GIS products and services stems from the archaic legal principles, dated rules, and traditions associated with information access. If allowed to prevail, much of the promise GIS has to offer will be thwarted. As a result, investments by both public and private entities will not generate the full range of benefits nor be as efficiently employed.

At this point in the evolution of electronic information dissemination, particularly information derived from GIS, there are few models for the 'right way' to manage this valuable resource. The private sector benefits from the focus of a profit motivation. Beyond questionable ethics, the 'right way' is measured by the bottom line, either from the direct sale of products and services or indirectly through the use of GIS products and services to achieve another end. The public sector has greater difficulty in characterizing the 'right way' for several reasons:

1. Public good is not measured in dollars and cents;
2. There is a body of law, procedures, and traditions that require information dissemination, regardless of its character, value, or subsequent use or utility; and
3. Moving beyond the current setting requires clarification or definition of public policy and establishing practices which mirror, in many ways, those of private enterprise.

Until public policymakers, both executive and legislative, address the legal and policy issues confronting GIS custodians, the potential of GIS to the general public and to the 'specific public', will be limited and public agencies will be at risk to control their destinies and to satisfy their legislated mandates. As a precursor to legislative initiatives, GIS custodians in government settings can establish a course of conduct in the development and dissemination of products and services that is responsive to the public good and recognizes the contemporary value of the public's informative assets. This course of conduct must, and can, be accomplished without jeopardizing a citizen's access to public records or breaching practices that protect confidential information.

Clearly, the initiative on the part of public organizations must reflect and address a broad range of issues, including, but not limited to:

1. Open records/public records laws add Federal Freedom of Information Act language and jurisdictional interpretations;
2. The experience of government to exercise proprietary authority;
3. Undue competition with private sector business;
4. Liability for information products and services;
5. Copyright law as applied to databases and products, and control of third-party use; and
6. Establishing prices for products and services.

Establishing a Course of Conduct

The assurance of accountability in government evolved from various federal, state, or provincial, and open records laws. Though there are substantive differences in the philosophy of cost recovery between Canadian and United States agencies, GIS custodians who are charged with disseminating information at rates that are dramatically lower than market value are positioned to service the commercial sector regardless of, and in conflict with, their other responsibilities to the public and are unduly subsidizing commercial ventures at the expense of the general public. Even the 'specific public' of commercial firms and individuals who can utilize digital information, and associated products and services in the short term may ultimately suffer if a public agency cannot sustain its ability to provide quality products and services in a timely manner. Moreover, if the agency is at a disadvantage in maintaining and improving the digital databases and supporting technology because of excessive demands on personnel or lack of funding or revenues, the inherent value of prior investments will decay.

Control of public access and options for cost recovery become the central issues for GIS custodians as the balance between undue commercial subsidies and assurances of accountability change with this new technology.

There is also a range of practical issues associated with the sale of products and services. Central to these is "What is the information worth? How is it computed? How can a public agency retain control, or share, in the worth of derivative value? And, how, procedurally and mechanically, are these information resources marketed?"

Government agencies will need to develop practices and skills that are second nature to private enterprise. Even so, price setting in the public domain must reflect policy considerations more complex than the private sector's focus on profit, frequently embodying considerations on partial recovery of costs, e.g., only operational cost elements, capital cost recovery, etc..

In addition, the organizations must become adept at sizing up and down service bureaus, if that becomes a function; projecting market demand for specific products and services; and servicing commercial, value-added firms and end-users alike. These are functions and experience sets that are unusual in government.

GIS organizations hoping to derive significant levels of revenue from the sales or licensing of products and services derived in part from GIS will need to conduct themselves in ways that have previously been the domain of commercial enterprises. More importantly, the conduct can establish the basis for the evolution of law, regulation, and tradition.

From the Other Side

From the consumer's perspective, the 'knee jerk' reaction is often negative, and interpreted to be demanding of payment where none was previously required. Taken in its broadest construct, the recovery of costs for the development of products and services achieves the same public purposes as other user fees, the fees are assessed to those who benefit from the specific service delivery.

In this manner, the GIS custodian agency is assured a revenue stream that is adequate to address the requirements that are in excess of its legislated and executive mandates to provide a given level of service or support. Individuals and organizations who cannot directly benefit from the value-added capabilities of GIS are not underwriting the commercial ventures of other organizations,as would be the case if the information was freely provided and the cost, therefore, embedded in the general tax and revenue sources of the government's entity.

Moreover, there are arguments that government may be better positioned to serve as an integrator of information, much of which is accumulated from transactions involving the GIS custodial agency and participating parties. Given the efficiencies that may result, GIS products and services can be provided to consumers, including commercial enterprises, with fee structures that permit both broader use of the information and allow commercial entities to develop a value-added market providing enhancements, repackaging, and other services as extensions.

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A Corporate Perspective for Treating Data as an Asset

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Abstract

The Washington Department of Natural Resources (DNR) manages three million acres of state uplands held in trust for forest, agriculture, urban and recreation use. The DNR's primary mission is to productively manage these trust lands to provide financial support to state institutions, mainly for school construction, through leases of land and the sale of timber. A geographic information system including a large database able to supply necessary information to meet managers' needs is critical to the success of the Department's mission.

The DNR data policy encourages sharing opportunities and allows for fees to be charged when one-way transfers of data occur. The policy states that the purpose is to build consistent data under the concept that data is a valuable resource to be shared, gathered, stored, processed and controlled efficiently and effectively. The policy further states that systems will be designed to collect data for the corporate benefit and provide information when, where and how it is needed. A data sales procedure outlines the steps for establishing fair market data prices and selling data. A data license agreement is used anytime there is a physical transfer of data to another organization.

There are at least five reasons for treating data as a commodity that may be bought, sold or traded at fair market rates. They include:

- investment opportunities;
- maintenance of existing data;
- pride of ownership (commitment to quality);
- knowing the true cost of operating programs; and,
- passing on the costs of sharing data.

The transition to a market place where data is viewed as a commodity will have many strengths and weaknesses. This author believes that in the long run the result will be vastly larger quantities of higher quality data available to meet the needs of the information age. Data providers will respond to new market opportunities. Software and hardware vendors will provide data access tools at substantially reduced prices as the demand for information grows in every segment of society.

Background

The Washington Department of Natural Resources (DNR) manages three million acres of state uplands held in trust for forest, agriculture, urban and recreation use. The DNR's primary mission is to productively manage these trust lands to provide financial support to state institutions, mainly for school construction, through leases of land and the sale of timber. More than 200 transactions each day take place on over 10 000 parcels of land. A geographic information system including a large database able to supply necessary information to meet managers' needs is critical to the success of the Department's mission.

The DNR is a proprietary as well as a governmental agency; it operates as a quasi-business, generating revenue. Yet it has regulatory responsibilities. Its corporate database policy is much like that of a major timber company. The database developed with trust funding to support trust responsibilities is therefore not in the public domain.

Data Availability

Five main data layers exist in the DNR geographic information system. The first contains political boundaries, public land survey lines, state and county ownership codes, administrative boundaries, and resource ownership codes. The second data layer contains data on land use and vegetative cover for all parcels managed by the DNR. Attributes of this data layer include stand numbers, species codes, physical measurements of timber and management assignments. The system also includes soils data on state and commercial forest lands. The DNR is adding road and hydrographic data layers.

Data as an Asset

The DNR data policy encourages sharing opportunities and allows for fees to be charged when one-way transfers of data occur. The policy states that the purpose is to build consistent data under the concept that data is a valuable resource to be shared, gathered, stored, processed and controlled efficiently and effectively. The policy further states that systems will be designed to collect data for the corporate benefit and provide information when, where and how it is needed. A data sales procedure outlines the steps for establishing fair market data prices and selling data. A data license agreement is used anytime there is a physical transfer of data to another organization.

There are at least five reasons for treating data as a commodity that may be bought, sold or traded at fair market rates. They are described in the following sections.

Investment Opportunities

Data providers must be able to forecast a market for products that will warrant investments of corporate resources. If there are investment opportunities, organizations will be encouraged to produce more data at higher quality. The result will be that there is more data available for use.

The DNR converted soil data for over 1100 public land survey townships from a mapping system to a geographic information system format in 1985. The cost of the project was $130 000 US for completing all of the conversion and editing of the data. The proprietary interest in the dataset was for soils on trust-managed lands only. The primary justification for converting the entire data set, including data not on trust lands, was for the opportunity to recover expenditures and generate revenue at a later date. The complete data set also provides an otherwise unavailable opportunity for trust land managers to look at management impacts on adjacent lands wi thin watersheds. The results are better management practices and soils data available for lands other than DNR managed trust lands.

Maintenance of Existing Data

Government programs often find it difficult to maintain data sets to sufficient standards to ensure their usefulness over time. Organizations that are able to fund data maintenance programs through data sales or user fees will be in a much better position to both justify and carry out these programs.

Pride of Ownership

Data specialist share the commitment of their co-workers to fulfill organizational missions. It is often difficult, however, when the results of their work achieves little recognition in the work place. A formal recognition in the true value of the work being completed is one of many opportunities in the work place to improve the employees' sense of pride in work and commitment to quality.

True Cost of Operating Programs

With the general view that data is a resource to be shared but not sold, the true costs of many data intensive government programs are either too high or too low, depending on which program was first to develop needed data. If the costs of collecting and maintaining data were distributed across programs, then true costs and benefits of these programs could be determined. The result would be informed decision making.

Costs of Sharing Data

There is a significant cost associated with developing and maintaining sharable data bases. The DNR has developed application programs to more efficiently create output datasets. The cost of making an investment to improve the efficiency of this operation could not be passed on to the individual or organization under many state open records laws. This is an issue of improved operating efficiency where records laws are imposing higher costs on many government programs.

Conclusion

The transition to a market place where data is viewed as a commodity will have many strengths and weaknesses. This author believes that in the long run the result will be vastly larger quantities of higher quality data available to meet the needs of the information age. Data providers will respond to new market opportunities. Software and hardware vendors will provide data access tools at substantially reduced prices as the demand for information grows in every segment of society.

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Some Major Legal Issues Affecting the Canadian GIS Model and Its Participants

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Introduction

It would be a difficult task to catalogue all of the legal issues arising from the development of a Geographic Information System (GIS) and then to provide a learned treatise on each. The task would be made all the more difficult in that the development of the law by Statute, those laws enacted by legislative bodies, or by Common Law, those laws developed through Court decisions, traditionally lags well behind new concepts or technologies such as those involved in the development or operation of the GIS model. Fortunately, the dictates of time and the bounds of the discussion at the GIS '91 Symposium are such that an exhaustive treatise on all legal issues involved with or affecting the GIS model is not possible, and certainly well beyond the abilities of the writer. Accordingly, I have chosen to confine my paper to some of the major legal issues and considerations affecting a Canadian participant in the GIS model.

I believe that some of the most important legal issues to be considered by participants in the GIS model are those relating to ownership of information and those issues relating to the responsibility borne by the information suppliers, the GIS administration, and the consumers of the information supplied by the GIS.

Issues of Ownership

Ownership of information, or a compilation of information, is often a difficult legal matter to determine. Part of the problem is that ownership implies that the subject over which ownership is claimed is, in fact, 'property'. Historically, Statute Law and Common Law have been rooted in questions involving ownership of tangible property rather than ownership of information or ideas, or even ascribing to information or ideas the qualities of property, as for example, the decision of Regina v. Offley 28 CCC (3d) 1, in which the Alberta Court of Appeal found that even confidential information did not fall within the definition of property to support a charge of theft. Some complain that even though the law does recognize the potential for information or ideas to be property or have qualities of property, the law does so only on the basis of principles or definitions that are too awkward to apply to the business of handling information, or that the law does not offer effective protection or remedies to those involved in handling information.

Nonetheless, the Common Law of trade secret and breach of confidence, and Statutes such as the Copyright Act, Patent Act and Trade Marks Act, and even amendments to the Criminal Code, have come to afford some measure of protection to those handling information.

Protection Under the Copyright Act

The Copyright Act, C.42, R.S.C. 1985, as amended, provides the owner of literary, dramatic, musical or artistic works with the exclusive right to produce, reproduce, record, adapt, translate or exhibit in public those works. The Copyright Act has undergone significant amendment in 1988 (C. 15, S.C. 1988) to include a definition of 'computer program' as being "a set of instructions or statements, expressed, fixed, embodied or stored in any manner, that is to be used directly or indirectly in a computer in order to bring about a specific result" and further defines literary works as including 'computer programs'. The Courts have considered the protection afforded a literary work by the Copyright Act and have found that "compilations of material produced by others may be protected by copyright, provided that the arrangement of the elements taken from other sources is the product of the Plaintiff's thought, selection and work".

Slumber-Magic Co. Ltd. v. Sleep-King Bed Co. (1984) 3 CPR (3d) 81 at 84 (BCSC) is an example of such a situaiton.

Under the Copyright Act, the owner of copyright is usually deemed to be the author, although the exceptions to this rule include an author who produces the work in the course of his employment; in which case the employer is found to be the owner of copyright (Section 13 (3) Copyright Act). The Copyright Act provides remedies to the owner of copyright for those infringing the owner's copyright and as a general rule defines infringement as occurring when any person does anything that only the owner of copyright has a right to do without, the owner's consent. The Copyright Act defines criminal offences for those infringing upon copyright and provides for penalties that have been increased under the 1988 amendment to fines of up to $25 000.00 or imprisonment for up to six months, in the case of a summary conviction on a charge of infringement and fines of up to $1 000 000.00 and imprisonment for up to five years on an indictable offence conviction.

Where the author of the work is not the owner of the copyright, the author still has moral rights which are set out at sections 12.1 and 12.2 of the Act. These moral rights include the right to be described as the author of a work and the right to prevent the work from being distorted, mutilated or otherwise modified or used in association with a product, service, cause or institution where the effect is to prejudice the honour or reputation of the author (Section 18.2 Copyright Act). While moral rights of the author cannot be assigned, these rights can be waived.

The advantages of copyright protection include the following:

a) A relatively simple and inexpensive system of registration under the Copyright Act, whereby a simple application form and a fee of $35.00 are forwarded to the Copyright Office;

b) Registration under the Act affords the owner of copyright the benefit of certain important presumptions including the presumption that the owner declared in the application is the actual owner of copyright and relieves the owner of the burden of proving ownership of the copyright in Court proceedings, unless evidence is led to challenge ownership of the copyright;

c) Copyright vests in the owner whether or not the owner registers under the Act and before the owner registers. Therefore, the owner can assert ownership in the copyright before the Certificate of Copyright is issued by the Copyright Office, before application is made, and before publication of the work. In fact, copyright is often simply evidenced by the owner's claim of copyright with the 'c within a circle' symbol, the name of the owner and the date of publication;

d) The Act affords the owner broad remedies against those infringing on the owner's copyright, including remedies of injunctions directing the destruction of infringing material, injunctions directing accounting for profits, and further provides for criminal sanctions against those infringing against copyright intentionally;

e) The term of protection offered by the Act is very long, usually being the life of the author plus 50 years; and,

f) Registration under the Copyright Act provides for some measure of international protection under various reciprocal copyright conventions.

The great problem of copyright protection is that it is a protection of the expression of an idea rather than protection of the idea itself. This is of crucial importance to those engaged in information sharing in that the question will arise as to whether the information being supplied is merely an idea which is unprotected by copyright or an expression of an idea which is protected by copyright. The failure of the Copyright Act to protect ideas is not accidental. Rather, the framers of the Act have specifically tried to prevent the Act from being an impediment to the free dissemination of ideas. Nonetheless, the absence of protection of ideas will be of concern to participants in the GIS, unsure of whether the information they are supplying and developing is an idea incapable of protection, or the expression of an idea that is protected by copyright.

The Patent Act

The Patent Act confers upon the inventor of a "new and useful art, process, machine, manufacture or composition of matter," or any improvement therein the right to prevent any other person from making, using or selling that invention for a period of 17 years. The inventor prepares and files with the Patent Office an application containing a detailed description of the invention. The inventor is entitled to registration of the patent, in most circumstances, if the patent is:

a) Novel;
b) Useful;
c) Contains an element of inventiveness and is of suitable subject matter; and
d) Is properly specified in the application.

Relying upon patent protection presents a host of difficulties to participants in the GIS. In the first place, the ability to patent a computer program is not clearly established, and in light of changes to the Copyright Act, applications would more likely be made for a copyright in a computer program rather than to attempt to patent a computer program. In addition, the Patent Act does not protect ownership to ideas. In fact, the Act expressly provides that a patent will not issue for an invention that is a 'mere scientific principal or abstract theorem' (Patent Act, Section 27 (3)). Furthermore, patenting is an expensive, slow process with issuance of a patent being no guarantee that entitlement to the patent will not subsequently be successfully challenged in any event. Finally, patenting in Canada of any invention usually requires that the inventor look to the patent laws of another jurisdiction, often the United States, where the patent will ultimately have to be protected. Accordingly, patent applications are often prosecuted both in Canada and the United State and require conformance to both jurisdictions. This becomes crucial in that American patent law demands a greater degree of non-disclosure prior to patent filing than does Canadian Law.

Trade Secret and Breach of Confidence

The law surrounding trade secrets and breach of confi-dence has developed through Common Law rather than by a Statutory codification. While the law with respect to breach of confidence and trade secrets is not co-extensive, for the purposes of this paper, both will be discussed as one topic.

The Courts will imply a duty upon a party receiving information to keep that information confidential where the following three elements exist:

1. The information received was confidential;
2. The information was communicated in confidence; and
3. The information was misused by the party to whom it was communicated.

Lac Minerals v. International Corona Resources Ltd. [1989] 2 S.C.R. 574 was pivotally concerned with these issuse.

The first hurdle to be overcome is proving that the information received was confidential. In this respect, the Courts have demonstrated a willingness to find that information is confidential even if it is in part public information, such as a patent filing or a geological test result or information that was capable of being discovered through reverse engineering or a diligent search.

The Courts next embark on consideration of the nature of the relationship between the parties to determine if the relationship imposed the obligation of confidence and that the obligation of confidence was breached.

The problem with the Law of Trade Secrets and Breach of Confidence is that it is Common Law, and parties trading information depend on the guidance of case law to determine their position in dealing with each other. Nonetheless, the Common Law of Trade Secret does offer a real possibility of protection to parties trading information under the GIS. For an excellent analysis of this subject matter, including proposed amendments to the Criminal Code regarding the unlawful use of trade secrets and a proposed 'Trade Secret Protection Act', see **Trade Secrets**, Report 46 of the Alberta Institute of Law Research and Reform, 1986.

Contractual Protection

Many of the vagaries of Common Law and Statute Law can be removed by contract as the Courts are involved to give effect to the bargain made between two or more parties. The protection afforded by contract will be of great importance to participants in the GIS. Parties exchanging information will want to ensure that at least the contract is reduced into writing, signed by all parties involved, and that the contract fully and accurately describes the three P's of contract law; parties, property and price. Some other major issues to be addressed by GIS participants would be as follows:

Employment Agreement

1. Does a firm trading information under the GIS need one in the first place?

2. Who will own the copyright for the information produced in the course of employment? The employee or the employer?

   Section 13 (3) of the Copyright Act deems the employer to own copyright in works prepared in the course of employment by an employee in the absence of an agreement to the contrary.

3. Are the author's moral rights under the Copyright Act waived by the employee in favour of the employer?

4. Is the employee subject to an obligation of confidence? If so, the contract should confirm that the work and information received or produced by the employee is proprietary in nature and a trade secret.

5. Is the employee subject to a non-competition covenant? Does the covenant survive termination of the employee's employment? If so, parties will want to ensure that the non-competition covenant is reasonable in both its term and the geographical area covered. The Courts will refuse to enforce an unreasonable non-competition covenant as being an unreasonable restraint on trade.

6. Is there an obligation on the part of the employee to warn of any work coming to his attention that infringes on the employer's copyright or any of the employer's other interests in the work?

Contracts with Third Parties

As a preliminary consideration, the party distributing information will want to consider how disclosures of the information affect the party's rights in the information; for example, later patenting in the United States or maintaining that the information is a trade secret. Some of the other considerations are as follows:

1. What is the nature of the agreement? Is it license, assignment or transfer?

2. How is the information characterized? The party maintaining ownership of the information will want to see that the contract describes the information as being proprietary and a trade secret.

3. Does the contract contain a covenant of confidentiality imposed upon the party receiving the information? Are there non-disclosure restrictions on who may review the information within the organization of the receiving party? For example, some agreements dealing with information or technology transfers provide that only certain named employees or a certain level of executive or technical employees may review the information being shared. Are third parties receiving the information required to sign a written covenant of non-disclosure?

4. Are there covenants dealing with submission of the information to the GIS? Is the receiving party able in turn to submit the information to the GIS? If so, who receives the remuneration payable by the GIS administration for such information? What responsibility is borne by the parties to the contract for claims arising from the use of the information, or even claims arising from submitting the information to the GIS?

5. What representations or warranties are made with respect to the information? Are there any warranties or representations at all? Are warranties such as fitness for the purpose intended, merchantability, etc. implied by the local Sale of Goods Act legislation? In Alberta, it is doubtful that the Sale of Goods Act would even apply to information given the wording of the definition of 'goods' covered by the Act.

6. Does the information sharing contract describe the standards employed by the party collecting the information in the course of the collection? Are those standards of data gathering to be disclosed to all other third parties who are in turn provided the information?

7. Should the contract contain exclusion clauses limiting the liability of the person providing information? Should there be a ceiling on the amount of the liability of the person providing the information? Will the person receiving the information have to disclose the exclusion clauses and bind third parties to the exclusion clauses? It should be noted that exclusion clauses are construed by the Courts narrowly against the party insisting on them. At a minimum, the Court will require the exclusion clause to be full and complete, and as a rule, expressly covering the type of loss suffered and will require that the exclusion clauses be specifically drawn to the attention of the other party at the time of the contract before they will be upheld.

8. What kinds of remedies should be included in the contract? Should the contract specifically refer to the availability of injunction for the return of all materials containing information, or any derivative, if the party receiving the information breaches the information sharing contract?

9. What law governs the contract? Have the parties agreed to submit any dispute to the Courts of that jurisdiction?

Contracts With the GIS Administration

The GIS administration would have to consider the same issues as outlined in Contracts with Third Parties section above and also the following considerations:

1. Can a party receiving information from the GIS re-submit that same information in a modified form or as part of a greater compilation of information?

2. If the answer is affirmative, what kind of disclosure must be made by the party re-submitting the information? Presumably, they would have to disclose the date and source of the information re-submitted to the GIS so that in the event of contradiction with other information, the most current information can be discerned.

3. How should the contracts be developed so as to conform with the statutory scheme governing the GIS Administration?

Responsibility of the GIS Administration and Suppliers of Information to Clients of the GIS

The contractual concerns outlined above obviously include concerns regarding the extent to which the information supplier or the GIS administration will be liable to a client of the GIS. One problem with contractual protection in the GIS is that the client suffering loss from use of GIS information may well not have any contract with the information supplier or even the GIS such that the contractual protection is available. Accordingly, contractual provisions such as exclusion clauses, limits on liability, disclosure of standards of information gathering, etc., may have no effect upon the claim advanced by injured clients of the GIS. This topic involves a consideration of the law of negligence. In order for the Plaintiff to succeed in a negligence claim, the Plaintiff must prove to the Court that the following elements exist:

1. That the Defendant owed a duty of care to the Plaintiff, whether within the context of contract or not;
2. That the Defendant failed to meet or discharge the standard of care;
3. That the Plaintiff suffered damage; and,
4. That the damage suffered by the Plaintiff was due to the Defendant's failure to meet his standard of care.

The duty of care owed by a Plaintiff to a Defendant is assessed by the Court in light of what is widely referred to as the 'neighbour principle'. If the Court finds that the Defendant was in sufficient proximity to the Plaintiff, as for example, in the case of two drivers sharing the road, that the Defendant should have contemplated as a reasonable man that others would be injured if the Defendant failed to exercise reason-able care in taking a particular step or refraining from taking a particular step, the Court will impose a duty of care on the Defendant.

In determining whether or not a Defendant has met the standard of care demanded, the Courts will have regard to what exactly that standard of care should be. The Court will determine the standard of care in light of the gravity of the risk of the Defendant's conduct, the practice or custom of persons in the same field of endeavour or activity as the Defendant, though it is no excuse for the Defendant to simply follow custom or practice where the custom or practice is found by the Courts to be deficient, and the expense or trouble involved in exercising precautions that might have avoided the injury to the Plaintiff.

It is common ground among most legal scholars that the boundaries for liability in negligence have been expanded significantly over time. This expansion of liability has been accompanied by a significant development in the Court's consideration of limitation periods that protect Defendant's claims being advanced after an unacceptable passage of time. In the decision of Central Trust Co. v. Rafuse (1986) 31 D.L.R. (4th) 481, the Supreme Court of Canada considered the Nova Scotia Statute of Limitations which provided that the Plaintiff had six years from the date the cause of action arose within which to bring its action for negligence against the Defendant lawyer. The lawyer's work that had been alleged to be deficient was completed in 1969. It was not until 1980 that the Plaintiff's claim was brought against the lawyer. Despite the six year limitation and the fact that eleven years had elapsed since the date of the work, the Supreme Court of Canada found that the Plaintiff's cause of action only arose at the time the Plaintiff knew or ought to have known through the exercise of reasonable diligence that the Defendant's work was performed negligently. The problem with the decision is that the 'discoverability rule' keeps alive many claims that would otherwise be barred by the passage of time. Theoretically, deficiencies in information supplied to the GIS could be discovered many years or even decades after the information was supplied. It is the balancing of risks among suppliers of information, the clients of the GIS administration and the GIS administration itself that requires attention in the legislative framework for the GIS.

Legislative Farmework for the GIS

It is uncertain that the GIS can exist without government legislation codifying its obligations, standards of conduct, and perhaps even its responsibilities to its clients. A useful example for the GIS might be a Torrens system of land registry. In a Torrens Land System, such as exists in Australia, Saskatchewan, Alberta and British Columbia, a land registry functions according to the guidance of three basis principals:

1. The Mirror Principle

   A person searching title need only examine the title certificate at the registry on which is recorded all interests affecting title. The Certificate accurately 'reflects' all interests, subject to certain limited exceptions, that affect the land. If an interest is to affect land, that interest must be registered with the land registry to be enforceable against third parties who rely on the registry to deal with the land.

2. The Curtain Principle

   A person searching title need not go behind the Certificate of Title to determine if there are other interests affecting the land described in the Certificate.

3. The Assurance Fund

   The administrators of the registry establish an assurance fund to protect those who are injured through defects in the land registry system. The fund is set in a certain amount by the legislature and all users of the registry pay a levy on each transaction with the registry. The levies are collected to support directly or indirectly the assurance fund's existence. In practice, the Assurance Fund in Alberta has been governed by provisions in the Land Titles Act which restrict the rights of those claiming against the Assurance Fund with respect to length of time within which claim must be brought or the amount that can be recovered (see section 164 - 169, and 171 of the Land Titles Act Chapter L-5, RSA 1980, as amended). I think that the Assurance Fund is a useful example for the proponents of the GIS in considering whether or not to limit the rights of those suffering loss through the operation of the GIS or information supplied by the GIS.

One would not expect that information suppliers would want to supply information to the GIS if supplying such information exposed them to incalculable dangers of a ruinous law suit. It is submitted that the GIS legislation will have to address whether or not there should be a ceiling on liability of the GIS administration, and even perhaps, the suppliers of information to the GIS, and will further have to address whether or not there must be a compromise of the property rights that would otherwise vest in suppliers of information to the GIS so that the GIS is free to disseminate information and be a truly useful body. If all suppliers of information to the GIS were to assert rights of copyright, trade secret, and insist on contractual agreements that narrowly restrict the use of their information by the GIS, it may well be that the GIS would soon lose its ability to function. More likely, the GIS legislation will have to somehow limit the property rights of the supplier after the information is supplied to the GIS to allow the information to be compiled with other information and distributed. Similarly, the legislation should define the rights of the client receiving the information in bringing claims against the GIS or other information suppliers.

The GIS Model presents another challenge to the law to balance the rights of suppliers, consumers and an administration with each other so that all can benefit from a system that is worthy of being fostered and developed.

Concurrent Session 7

Forest Management - Wood Supply and Harvesting

GISFORMAN—A Next Generation Wood Supply Model

Resource Management Planning - Linking a Land Information System to a Harvest Scheduling Model

Modeling the Visual Impact of Forest Harvesting: an Integrated Approach

GIS'91

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GISFORMAN - A Next Generation Wood Supply Model

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Abstract

This paper describes the design, operation and performance characteristics of a new spatial wood supply simulation model. Indicative of the next generation, the new model, GISFORMAN, is a revision and extension of the original FORMAN simulation modelling concept. This paper notes that GISFORMAN is unlike most current wood supply models in two important respects. First, GISFORMAN produces forest forecasts based upon stand-level information as opposed to stand aggregate (stratum) information. Second, by accessing a topologically structured spatial database, i.e., a GIS database, the model permits the inclusion of relative geographic positions of stands in developing and testing strategies. The paper points out that these two characteristics are significant. For one, it notes that maintenance of individual stand identity produces stand-by-stand management schedules that are easily translated into maps by a GIS. Further, the paper notes that since GISFORMAN has access to relative geographic positions of component forest stands, it is capable of producing management schedules and performance indicators that reflect the geographic context as well as the condition of those stands. Using results from a series of model runs involving a 9600-stand forest, ARC/INFO and a SUN 4/110 workstation computer, the paper illustrates and discusses GISFORMAN's new wood supply analysis capability. The effects of economics (harvest blocking and road cost) and wildlife habitat considerations (harvest block size and green-up) on wood supply are identified, quantified and discussed. Finally, the paper concludes that GISFORMAN has contributed to the advancement and refinement of wood supply modelling techniques. By providing harvest queuing rules that permit control of the geographic distribution of a harvest, in addition to the traditional rules that permit control of distribution of a harvest across inventory types, GISFORMAN is a true spatial model that has established the first span of a bridge to link strategic planning to on-the-ground management design.

Introduction

A forest is managed by controlling its structural change over time, that is, the change in distribution of its stand development types and stages.

Controlling the structure of a forest is the focus of management since it determines the availability of quantities and qualities of timber, wildlife, water and recreation. Control is attempted through the orchestrated application of interventions (harvesting and silviculture). Interventions alter forest structure either immediately, by changing stand development stages, or later, through their effect on timing of stand development patterns. Designing a schedule of interventions that achieves and maintains a desired future forest structure is the focus of forest management planning decision-making.

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The ability to project a present forest inventory forward, to forecast, is crucial to management decision-making for wood and wildlife habitat supply (Jordan and Erdle, 1989). A mix of *types, amounts, timings and locations of harvest and silviculture* defines an intervention schedule (or management design) and determines forest structural change and thus the future supplies of wood and habitat. However, the very large number of possible schedules and their associated forest responses create a difficult and complex decision-making environment. The need to test, before actual implementation, the effect of various harvest and silviculture schedules on timber flow and habitat availability is crucial to strategic planning and successful forest management design. In Canada, over the last decade, simulation modelling techniques have proven useful in this regard.

WOSFOP, OWOSFOP, NORMAN, FEM and FORMAN are some of the better known Canadian models that share a common modelling process and strategic planning focus (Figure 1). All are inventory projection models that forecast growing stock (m^3) by tracking stand aggregates (hectares of common development type) according to volume development over time as a specified management strategy is applied in a controlled and measured manner across a model forest. While the models differ greatly in the specific intervention queuing rules available for management strategy formation, all provide control over the *types, amounts and timings* of interventions. For a given strategy the forecasting process determines sustainable wood supply and translates it into a harvest schedule for implementation. Typically, dozens of strategies are formed, tested and forest responses analyzed for wood supply. Not surprisingly the process is frequently termed 'wood supply analysis'.

Unfortunately, simulation models developed in the 1980s are characterised by an aspatial approach that lacks location-specific resolution. Modelling and forecasting of forest structure is limited to the numeric (aspatial) distribution of stand development types and stages. This results in two drawbacks. First, the models lack queuing rules for controlling the *locations*, either absolute or relative, of interventions. This limits the models to aspatial harvest and silviculture strategies that do not determine a true assessment of wood supply and ignore wildlife habitat considerations completely. Second, today's models produce aspatial forest response indicators and implementation schedules that are awkward, at best, to transform into operationally acceptable, on-the-ground, management design. While today's models are sufficient for defining and developing aspatial management design strategies for wood supply, they lack consideration of the geographic structure of forests and are insufficient for design of wildlife sensitive and operationally, i.e., economically, acceptable management.

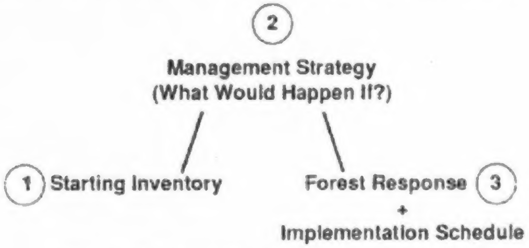


Figure 1. The simulation modelling process in forest management decision-making.

The current state of wood supply modelling is not surprising. Today's models were first programmed almost ten years ago. Timber inventories of the time were characterised by a computer-based numeric component, the numeric forest structure, and a non-digital map-based geographic component. The lack of geographic information in digital form precluded its use in wood supply modelling. Today, however, computer and database technology is such that digital timber inventories with both numeric and geographic components are not only feasible, but commonplace. For example, using a commercial GIS, in 1987 the Province of New Brunswick completed a province-wide inventory begun in 1982.

Models that consider both numeric and geographic forest structure in forecasting, spatial models, are now a possibility. This paper describes such a model and demonstrates its application in wood supply analysis. Called GISFORMAN (Geographic Information System linked FORest MANagement), it was researched and developed at UNB's Faculty of Forestry (Baskent, 1990).

GISFORMAN Design, Forecasting and Performance Characteristics

GISFORMAN is an extension of the original FORMAN modelling concept and design (Wang et al, 1987). While maintaining the look and feel as well as all the aspatial scheduling capability of its namesake, GISFORMAN, unlike FORMAN, relies upon a GIS database to provide absolute and relative positions of stands as well as their conditions. The model employs these data to: (i) incorporate geographic forest structure in starting inventory and throughout forecasting; (ii) support geographically-based economic and wildlife habitat-sensitive harvest strategies, and (iii) produce location-specific, map-based schedules. The model was programmed using the ARC/INFO™ GIS, the FORTRAN programming language and the UNIX™ operating system running on a SUN 4/110 workstation. While the particular hardware and software components are in common use in the Canadian forestry community (Dick and Jordan, 1990), the model design and functions transcend specific GIS software and hardware.

Starting Inventory

A spatial model like GISFORMAN requires a starting inventory that captures geographic as well as numeric structure of a forest's stand development types and stages. An appropriate representation of geographic structure would be one that permitted the model to more closely mimic actual harvest schedule decision making. The economics of harvest extraction dictate that operable volume amounts have to be geographically concentrated as a function of relative positions of stand development types and stages. Widely dispersed amounts will be more expensive than those that are geographically concentrated. Traditional North American harvest operations have long recognized this reality and have developed harvest schedules consisting of temporally and spatially distributed harvest blocks that group neighbouring stands together for harvest such that operable volume is geographically concentrated around a shared operating road network. The approach is used to control operating road cost ($\$/m^3$) — one component of extraction cost — by forming and scheduling for harvest only harvest blocks that have an acceptable operating road cost. To complicate matters further, not all extractable volume is available due to wildlife habitat considerations. Habitat considerations limit the size and availability of harvest blocks. In many jurisdictions, harvest block sizes are limited for this reason (in New Brunswick to 125 ha). This means that blocks in a harvest period must not exceed a specified area, nor can adjacent blocks, in consecutive periods, be harvested. These constraints obviously have the potential to further reduce wood supply across a forest at any time since they reduce the number of harvest blocks available for harvest. All said, it is apparent, therefore, that in order for a spatial model to control harvesting and calculation of wood supply in the manner just described, a starting inventory would have to characterize each stand, not only by its state, but that of its neighbours as well.

While GISFORMAN could directly access stand states and geographic locations from a GIS database, it could not access neighbourhood detail. It was found possible, though, to assemble the necessary neighbourhood detail using the stand topology (what's next to what) maintained in a GIS database. However, except to change neighbourhood sizes (harvest block size limits) stand neighbourhood information would not change for a given forest and would not have to be re-computed before each forecast. For this reason a separate program (CALCADJ), external to GISFORMAN, was developed to extend GIS database topology with lists of neighbouring stands for all stands in a forest. GISFORMAN was left with the tasks of using this neighbourhood detail to assemble harvest blocks, to characterize them in terms of size, volume content and operating road cost, to schedule their harvest with timber economics and wildlife habitat in mind and finally, to output the resultant spatial forest response and implementation schedule.

Management Strategy

Not unlike other wood supply simulation models, GISFORMAN forecasts forest development over time in response to a management strategy. In GISFORMAN, volume concentration and operating road cost values, calculated for each stand in a subject forest, as well as maximum block size and adjacency delay constraints, provide a basis for accommodating geographically-based economic and wildlife habitat-sensitive harvest strategies (Baskent, 1990). Specifically, GISFORMAN implements three new harvest queuing rules, Rules 8, 9 and 10, in addition to the seven aspatial rules provided in the original FORMAN. Using Rule 8, stands and their neighbours (harvest blocks), may be queued for harvest to minimize operating road cost ($\$/m^3$) across a forest for each planning period. With this queuing strategy, stands are given a chance to become not only operable but also economically extractable before harvest. Harvesting is concentrated in geographic areas where there is more operable volume, (more volume per hectare and thus less operating road cost). Or, using Rule 9, blocks may be queued to maximize volume concentration (m^3). With this rule, harvesting is concentrated in geographic areas with the greatest operable volume, regardless of operating road cost. Rule 10, may be used to capture harvest block volume loss due to natural mortality. Here, harvesting is mostly concentrated in geographic areas where the stands are of older development stages. Lastly, GISFORMAN permits economic and wildlife habitat limits to be specified. Maximum operating road cost, maximum block opening size and adjacency delay limits may be combined with Rules 8, 9 and 10 to form strategies that effect control of the geographic distribution of harvest and determine wood supply on both economic and biologic bases.

Forest Response and Implementation Schedule

GISFORMAN forecasts, on a period-by-period (5 years, usually) basis, forest response to harvesting and silviculture of specific *types*, *amounts*, *timings* and geographic *locations*. Unlike aspatial wood supply models, GISFORMAN produces performance indicators that reflect geographic structure of a forest and translates management strategies into mapped schedules. New performance indicators, effective growing stock (economic and unconstrained forest volume) and average operating road cost are produced, along with statistics such as number of blocks harvested, average number of stands per block and average block size for each period. Optionally, using ARC/INFO's ARCPLOT display subsystem capabilities, treatment periods for harvested, planted and spaced stands can be mapped for the entire simulation or for any period . With this map display, the geographic location and distribution of actual harvest blocks over the forest is evident, as in Figure 2.

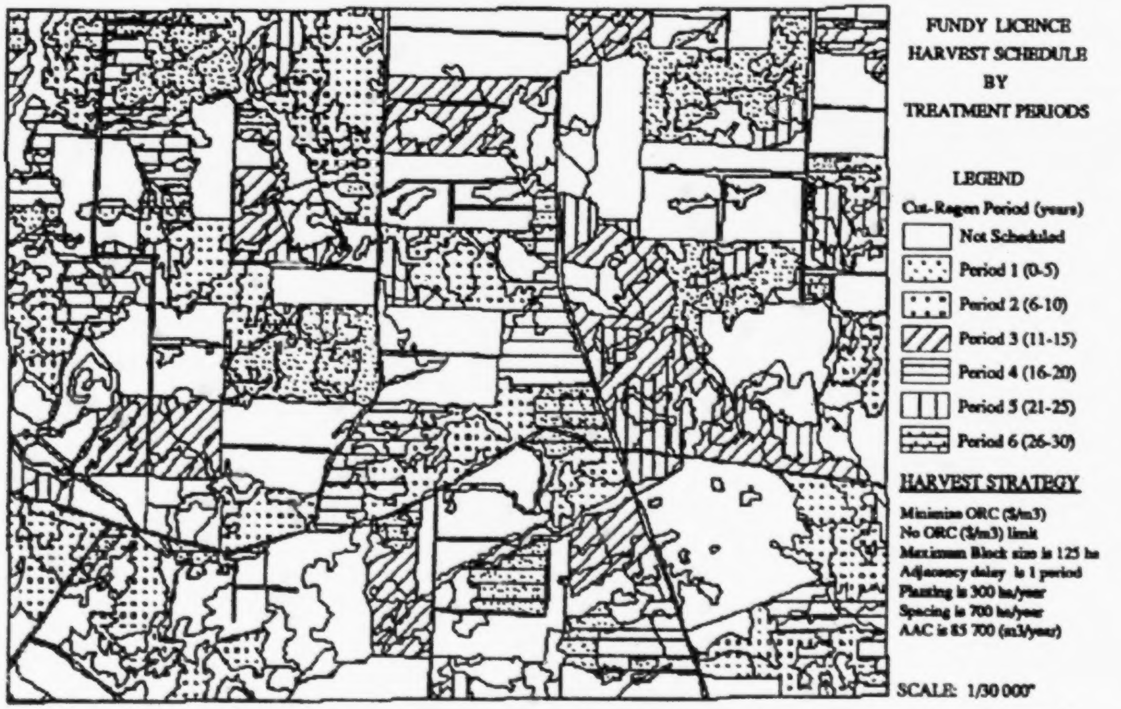

FUNDY LICENCE
HARVEST SCHEDULE
BY
TREATMENT PERIODS
LEGEND
Cut-Regen Period (years)
Not Scheduled
Period 1 (0-5)
Period 2 (6-10)
Period 3 (11-15)
Period 4 (16-20)
Period 5 (21-25)
Period 6 (26-30)
HARVEST STRATEGY
Minimize ORC ($/m3)
No ORC ($/m3) limit
Maximum Block size is 125 ha
Adjacency delay is 1 period
Planting is 300 ha/year
Spacing is 700 ha/year
AAC is 85 700 (m3/year)
SCALE: 1/30 000"

Figure 2. A map, E5746, of the New Brunswick provincial map series, illustrating a block harvest schedule produced by GISFORMAN.

Performance

GISFORMAN was tested on a 9600-stand forest in New Brunswick. Results showed that the model takes about two hours to complete an 80-year forecast using a 7 MIPS Sun 4/110 workstation computer with SCSI disk interface. However, since model performance is mostly dependent upon disk I/O, results will vary greatly depending upon memory buffering capacity and disk drive throughput characteristics.

The model does not use computer memory to store stand information. The size of forest, in terms of the number of stands, is only limited by mass storage capacity. Typical Canadian forests should be easily accommodated with 0.5 to 1 gigabyte of mass storage.

GISFORMAN Wood Supply Analysis

GISFORMAN was used to conduct a wood supply analysis for a portion of a New Brunswick Crown Licence. The Canaan area, managed by J.D. Irving Ltd, covers a forest area of 111 296 ha (72 526 ha productive forest) in east-central New Brunswick (Figure 3). The Canaan wood supply area consists of 15 975 stands, of which 9 640 are productive, and is covered by 26 provincial forest covertype maps. The provincial database of covertype maps, in the form of ARC/INFO coverages, provided forest inventory consisting of stand attributes, locations and topology.

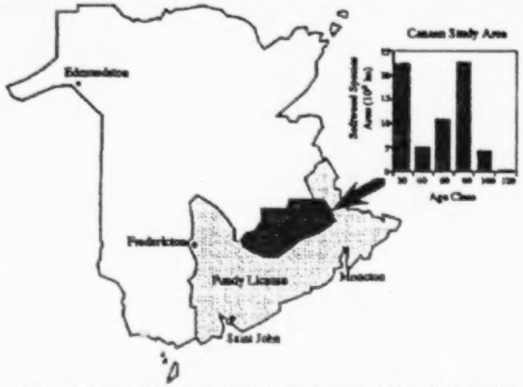

Edmundston
Fredericton
Fundy Licence
Moncton
Saint John
Canaan Study Area
Softwood Species Area (10³ ha)
Age Class

Figure 3. The Canaan forest in east central New Brunswick.

The results of the analysis, shown in Table 1, permit a comparison of spatially (Strategies 1-6) and aspatially (Control Strategy) determined wood supplies, and an opportunity to isolate and quantify the effects of economics and wildlife habitat considerations on sustainable wood supply.

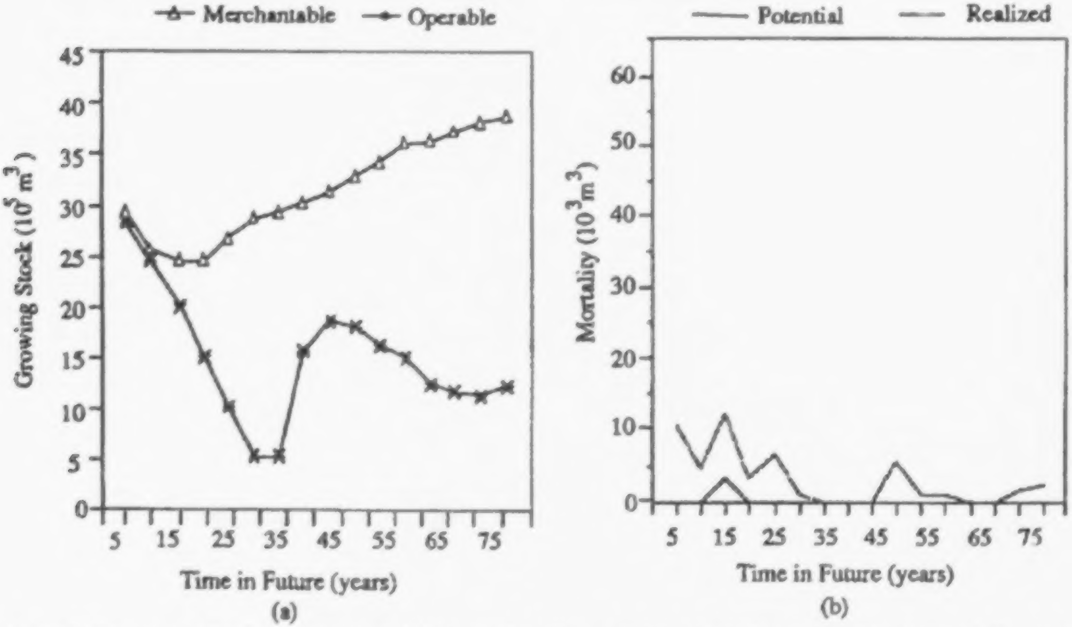
Table 1. Summary of the Canaan Forest Wood Supply Analysis

† Strategy #	Operating Harvest Rule	Adjacency Road Cost ($/m³)	Sustained Delay (# of periods)	Reduction Harvest Level (m³/year)	versus Control (%)
Control	1	0	0	**102 000**	0.0
1	8	no limit	0	97 000	4.9
2	8	no limit	1	85 700	15.9
3	8	15	0	93 200	8.6
4	10	no limit	0	94 000	7.8
5	10	no limit	1	84 000	17.6
6	10	15	0	91 000	10.7

† maximum opening size is 125 ha for all strategies

Economic Effects

Since all the strategies implemented block-by-block harvesting, as opposed to stand or hectare harvesting, all incorporate a reduction in sustainable harvest level due to blocking. This reduction is, however, harvesting rule-dependent. In Table 1, it is indicated that Strategies 1 and 4 produced 4.9% and 7.8% harvest reductions respectively. These are attributable to blocking as well as the harvest rule, since neither an operating road cost limit nor an adjacency delay are involved. There are two main reasons that explain the reductions. First, with GISFORMAN, if a stand is harvested its operable neighbours are also harvested, regardless of their development stage, to form a harvest block. Therefore, some stands that have not reached peak volume are harvested before other stands that are in decline. Blocking sacrifices mortality losses, as can be seen by comparing Figures 5b and 6b to Figure 4b, and predictably results in a reduced sustainable harvest level. The difference in operable growing stock levels found in comparing Figures 5a and 6a to Figure 4a confirms this fact as well. Besides the blocking effect, an additional reason for the reductions is related to the nature of the harvest rules. In Strategy 1, blocks were queued on the basis of operating road cost (cheapest first) as opposed to volume loss (greatest first). Thus some mature stands were left to decline before harvest. The failure of Rule 8 to control mortality losses (Figure 5b) results in the harvest level reduction. In Strategy 4, on the other hand, Rule 10 forced blocks of older stands which had less volume per hectare to be harvested first and as a result more blocks were needed for harvesting to meet the given harvest level. The more blocks cut, the more maximum opening size conflicts. Therefore, more stands became unavailable for harvesting, and larger gaps occurred between operable and effective growing stocks with Strategy 4 versus Strategy 1.



(a) (b)

Figure 4. The results of the Control strategy (minimize stand mortality, no operating road cost limit and adjacency delay constraint).

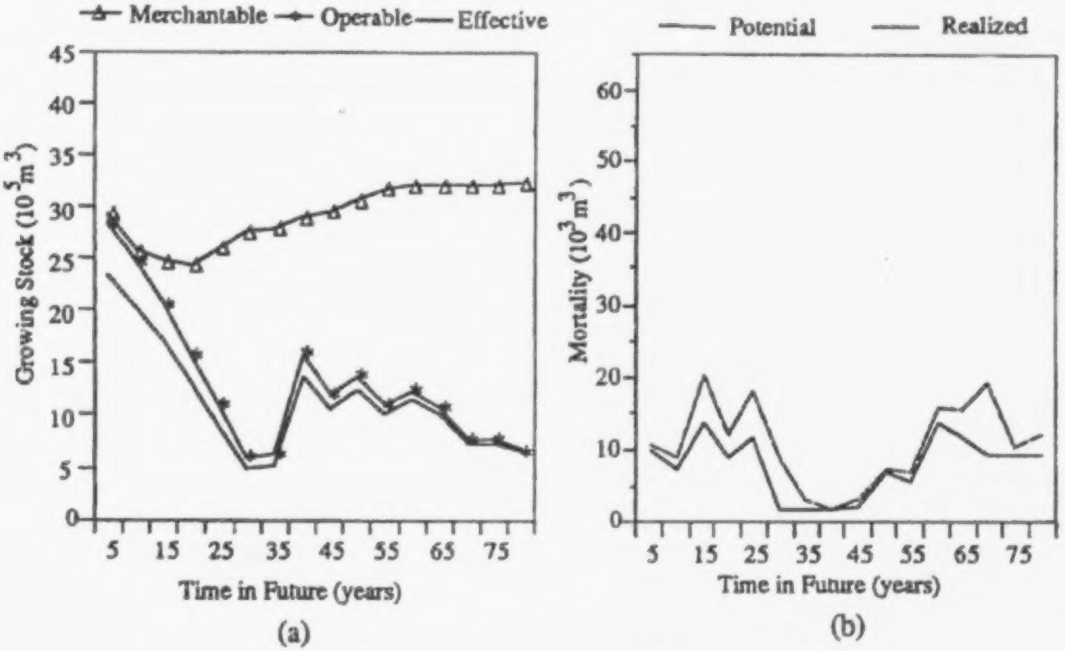


Figure 5. The results of Strategy 1 (minimize operating road cost, no adjacency delay).

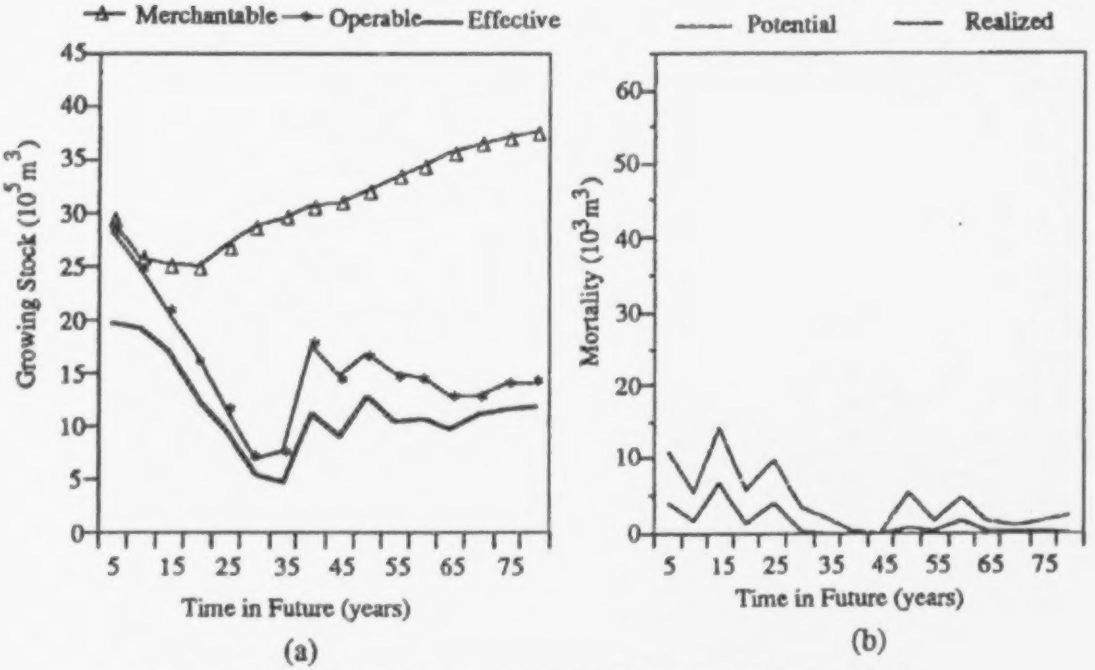
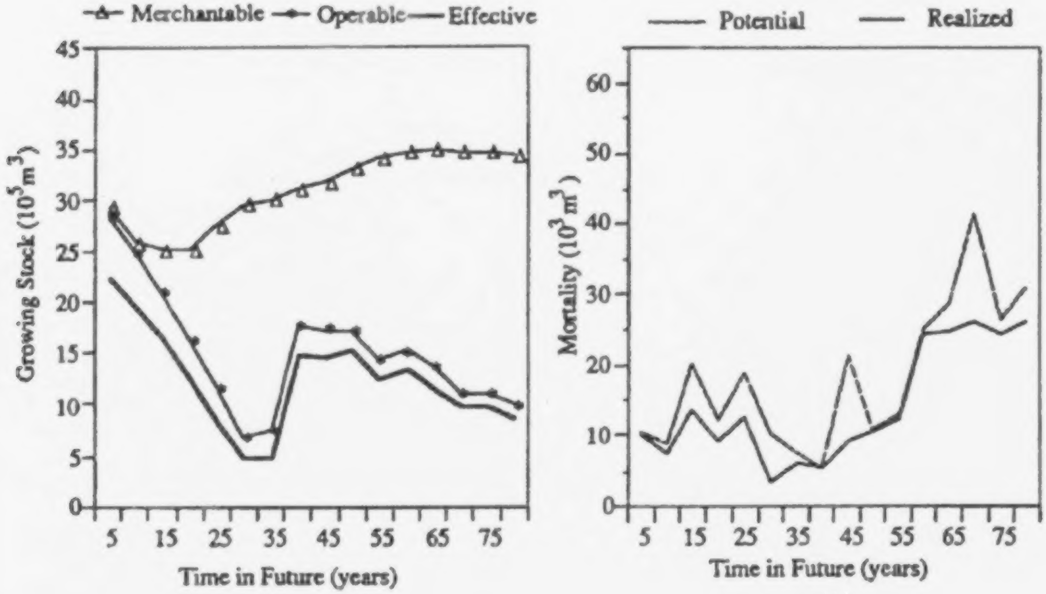
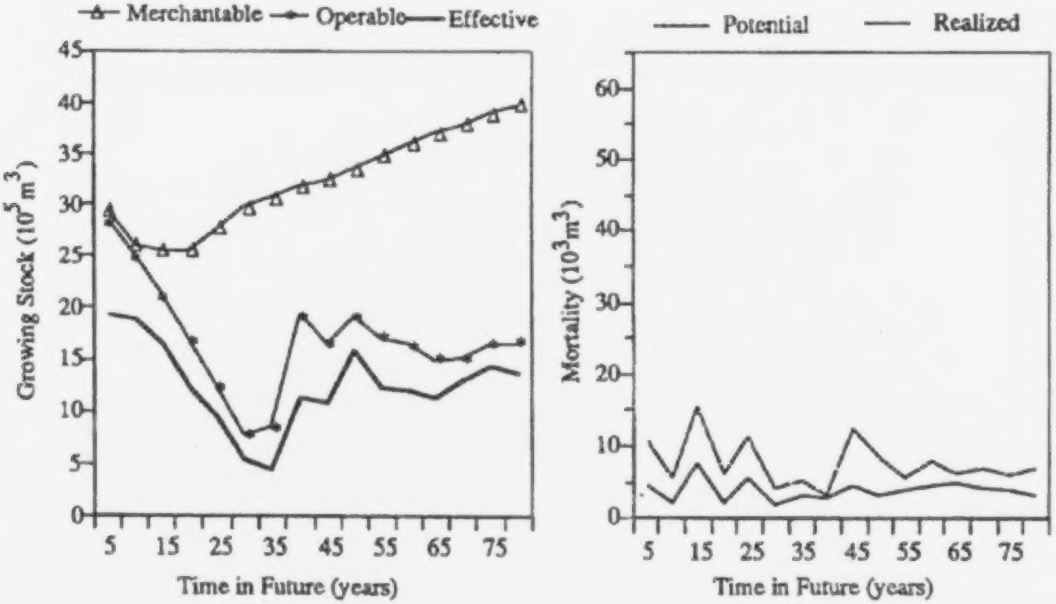


Figure 6. The results of Strategy 4 (minimize harvest block mortality, no adjacency delay).



(a) (b)

Figure 7. The results of Strategy 3 (minimize operating road cost, maximum $15/m3 operating road cost limit).



(a) (b)

Figure 8. The results of Strategy 6 (minimize harvest block mortality, maximum $15/m3 operating road cost limit).

The effect of operating road cost is also rule-dependent. When Strategies 3 and 6 are compared, reductions in sustainable harvest level of 8.6% and 10.7% respectively are found. Strategy 3, Rule 8 with a maximum operating road cost limit of $15/m³, reduced the sustainable harvest level an additional 3.7% (8.6%-4.9%) from Strategy 1. Besides the reasons provided for Strategy 1, the 3.7% reduction was merely due to the maximum $15/m³ operating road cost limit. Blocks exceeding the limit were considered unavailable for harvest and did not contribute to effective growing stock, thus contributing to the difference between operable and effective growing stocks (Figure 7a). Strategy 6, Rule 10 with a maximum $15/m³ operating road cost limit, reduced the sustainable harvest level an additional 2.9% (10.7%-7.8%) from Strategy 4. Besides the reasons provided for Strategy 4, the additional reduction was due to the maximum $15/m³ operating road cost limit as also explained for its pair, Strategy 3. Differences between operable and effective growing stocks (Figure 8a) show the fact that some harvest blocks exceeded the $15/m³ operating road cost limit and were considered unavailable for harvesting during the simulation, resulting in an additional 2.9% reduction in harvest level.

Wildlife Effects

Additional reductions in sustainable harvest level, beyond that attributable to blocking and operating road cost effects, will depend upon maximum block size and adjacency delay limits. The fact that a maximum block opening constraint exists (125 ha) means that any stand adjacent to a harvest block cannot be harvested in the same period, regardless of the harvesting rule. The specific effect of an adjacency delay on sustainable harvest is found by examining the results of Strategies 2 and 5. Reductions in sustainable harvest level of 15.9% and 17.6 % are noted. An adjacency delay of even 5 years has an obvious negative impact on sustainable harvest, regardless of the rule, since it greatly limits the availability of stands for harvest, thus reducing effective growing stock.

Summary

The way that merchantable and harvestable wood quantities and qualities are geographically located, relative to one another, determines their availability. Wood supply is limited to those merchantable timber amounts that are both economically extractable and not required to maintain wildlife habitat. However, conventional wood supply models lack any consideration of geographic forest structure (distribution of stand development types and stages) necessary to include economics and wildlife into the forecasting process. They provide, in fact, an overestimate of sustainable wood supply.

This paper has described the design and performance characteristics of a new generation of wood supply model, a spatial (GIS-based) model, that incorporates geographic forest structure in the starting inventory, strategy formation and forecast response for a truer assessment of wood supply. As demonstrated in an actual wood supply analysis, the GISFORMAN model opens up the opportunity to deal simultaneously with operationally important economic and wildlife issues, and to quantify any tradeoffs in the wood supply analysis. The model's ability to translate management strategies into operational mapped schedules further increases its appeal.

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Resource Management Planning - Linking a Land Information System to a Harvest Scheduling Model

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Abstract

The Bureau of Land Management has developed a Land Information System (LIS) which is providing the key information necessary for evaluating alternative management plans for the next decade. This paper outlines the manner in which Bureau personnel are using the LIS to determine available timber inventory for formulation of a harvest scheduling model and then to relate the harvest to actual sale units distributed in the landscape. The resulting linkages between the LIS and harvest scheduling model are crucial for environmental impact analysis.

Introduction

For the past three years, the Bureau of Land Management (BLM) in Western Oregon has been developing a digital database the of land under its administrative control in Western Oregon. This database has come to be called the Western Oregon Digital Database, or WODDB. The long-term goal for WODDB is that it will augment an operational land information system which will allow improved information management and better integrated decision-making in the near future. However, its current mission is to define the extent of protected versus intensively managed acreage and the environmental impact of implementing the resulting allowable sale quantity, or allowable cut for, the next 10 years into the 21st Century.

The six Management Districts in Western Oregon consist of approximately 2.1 million acres of forest land. The timber base in these Districts is further subdivided into 12 separate Sustained Yield Units (SYU) by legislative mandate. Districts have as many as four and as few as one SYU under their jurisdiction. As the name for the SYUs implies, the harvest level for the next decade must be calculated based on the mathematical sustainability of the allowable sale quantity, maintained over the next two centuries. The current planning effort by the Bureau is focused on generating harvest plans for each of the dozen SYUs combined with summary management plans for all six of the Districts involved.

The level of timber volume which can be harvested during the implementation of the Resource Management Planning (RMP) is dependent on a number of factors. The quantity of available inventory, its growth rates if left unharvested, the level of enhanced growth possible if silvicultural investments are made to existing stands and the expected productivity of future stands once the sites are harvested and regenerated are the most obvious factors. However, in today's world with its increased awareness of threatened and endangered species, loss of original unmanaged forest ecosystems, and competing interests for use of public lands, other political factors play an important role in defining these timber oriented factors.

Background

The manner in which the Bureau has approached this natural resource planning problem has been to rely on an open, yet complex planning strategy. The planning process has been open to the extent that the public as well as specifically known interest groups have been contacted and solicited for their advice and concerns. The level of public interaction was begun in the late '80s and will continue to expand as the process moves toward a final decision. In 1988 a publication was released, referred to as the **State Guidance**, which explained the Bureau's procedures and positions on a number of land use issues central to the planning effort.

The purpose of the **State Guidance** was to explain the options available to planners in creating different land use allocations. The format implemented by the Bureau is a fairly common procedure for evaluating a wide range of complex and integrated issues. The available forest inventory, relative to intensive timber management, ranges between two extremes. The initial alternative management plan (A) assumed that nearly all of the forest inventory could be intensively managed for timber production, and that the silvicultural treatments could be as intensive as they are financially prudent. This alternative has been nicknamed the Maximum Timber Run since it identifies the upper extreme of both timber land availability as well as timber productivity.

The Bureau's alternative at the other end of the land use spectrum (E), emphasizes old-growth protection, non-market forest uses and a less intensive style of timber management. This alternative represents timber production as a residual product, in that the timber produced would be as a result of activities more geared at producing specific types and combinations of ecosystems/habitats, than the activities are aimed at generating the most wood volume in the shortest amount of time. The other three alternative form a progression between these two extremes.

Alternative B attempts to increase wildlife protection and recreation use only on Public Domain (PD) lands or on Oregon & California (O&C) lands where their protection or use is most critical. Alternative C increases the focus on maintaining plant and animal biodiversity, both in the form of specific site protection as well as through modified silvicultural treatments of specific forest stands. Recreational forest use also increases its importance in this alternative. Alternative D is built around the central concept of implementing the ISC, or Thomas Report, which at this time appears to be the preferred recovery plan for the Northern Spotted Owl.

The sites selected for protection or for reduced timber emphasis will reduce the availability of land for intensive timber management. Additionally, the intensity of timber management on the remaining inventory is also influenced. The **State Guidance** provides planners with a mosaic of issues and with spatially-oriented implications for timber inventory availability. The current planning effort is really only possible with the WODDB, both for defining the spatial relationships inherent in the issues at hand and for relating the environmental impact resulting from harvesting the many sale units required to meet the allowable sale quantity during the next decade. The following sections will present the procedures being adapted to the Bureau's planning effort.

The key concept in the manner in which the Bureau is developing it's 1990's RMP is that the land use options are declared before the timber harvest scheduling or environmental impact analysis are calculated. The latter impacts are prefaced on the decisions made prior in the process. Therefore, the five alternatives are designed to represent a range of land use options and the numerical analyses determine the outcomes of these decisions. The methodology does not seek to determine the 'optimal' mix of products and consequences, rather, it only evaluates their net interactions on the estimated allowable cut and the resulting environmental impacts.

The following presents a brief list taken from the **State Guidance** of the goals and primary objectives for three of the five alternatives to be evaluated. The three are presented to provide the reader with the degree of change present in the alternatives.

Alternative A

Goal: Emphasize high production of timber and other economically important values on all lands to contribute to community stability.

Objectives:

- Produce the highest sustained yield of timber on all suitable forest lands legally available for harvest.
- Contribute to ecological functions important to timber productivity and to habitat diversity to the extent possible, consistent with the allocation for timber production.
- Manage threatened and endangered species habitat as legally required.
- Manage appropriate Congressionally designated areas to maintain and enhance their scenic values.
- Meet legal requirements for protection of wetlands and water quality, to protect anadromous fish habitat and other relevant values.
- Emphasize substantial developed and dispersed motorized recreation uses.
- Find no additional rivers suitable for designation under the Wild and Scenic Rivers Act.
- make land tenure adjustments which enhance BLM long-term sustained yield timber harvest opportunities.
- Provide no special management in rural (residential) interface areas.

Alternative C

Goal: Provide timber production to contribute to community consistent with the maintenance of biological diversity and the variety of other uses such as fish and wildlife habitat, recreation, and scenic resources on all lands.

Objectives:

- Produce a moderate sustained yield of timber.
- Provide biological diversity using a system that maintains some old growth and mature forest, focusing on protection of areas where special status plant and animal species cluster.
- Protect habitat of all threatened and endangered species and species with high potential for listing. Protect habitat of other species of substantial concern through the emphasis on biological diversity and to the extent consistent with moderate timber production.
- Retain existing RNAs and ACECs. Provide new ones from eligible areas except where lands managed by others are considered to provide more appropriate opportunities.
- Manage scenic resources in selected areas of high use areas, particularly emphasizing protection in corridors of existing and proposed wild and scenic rivers and major trails.
- Provide substantial protection for anadromous fish habitat, other substantial streams, and other water environment.
- Provide for a wide range of recreation opportunities emphasizing dispersed use, while reducing conflicts among recreation user groups.
- Find eligible river segments suitable for designation as scenic or recreational, if they are important and manageable, and designation would not cause adverse economic impact.
- Make land tenure adjustments to benefit a variety of uses and values.
- Adopt appropriate special forest management practices in rural interface areas zoned for moderate or high density residential occupancy.

Alternative E

Goal: Emphasize protection of older forests and management and enhancement of values such as dispersed non-motorized recreation opportunities and scenic resources.

Objectives:

- Produce a sustained yield of timber consistent with allocations for other uses and values.
- Protect all old growth and older mature forests.
- Protect habitat of all threatened and endangered species, species with high potential for listing and species of recognized concern.
- Retain existing RNAs and ACECs and designate all eligible areas.
- Manage all identified scenic resources and provide some visual resources protection for all lands.
- Manage all riparian areas and wetlands to maintain and improve water quality and fisheries habitat, and contribute to wildlife habitat diversity.
- Emphasize dispersed non-motorized recreation opportunities.
- Find all eligible river segments suitable for designation as wild, scenic, and recreational rivers.
- Make land tenure adjustments which would emphasize enhancement of non-timber uses and values.
- Adopt special timber harvest and forest management practices extensively buffering rural interface areas zoned for moderate or high density residential occupancy and other rural interface areas as appropriate.

While the objectives and goals provide the overall flavor of each of the alternatives, it is the carefully stated instructions in the **State Guidance** for a set of eleven 'issues' which actually guide the definition of the spatial resolution of the timber inventory. The following section will present these issues as well as the manner in which they direct the development of the timber inventory for Alternative C.

Defining the Inventory

Defining the intensive inventory base for Alternative C requires both automated GIS analysis as well as human interaction and decision-making on the part of District personnel. The Districts have a responsibility for participating in the determination of which sites will be protected 'up-front' for non-timber uses in the alternative. A three-stage approach was been devised and instituted for the purpose of defining the intensive forest inventory available to the harvest scheduling model.

Step 1: Before any WODDB processing can be initiated, the District Planning and GIS Coordinators are responsible for working with other District and/or Resource Area personnel for the purpose of determining which specific features in the Recreation (REC), Special River Designation (SRD), Visual Resource Management (VRM), State & Federal Highways (SFH) and the set of plant and animal themes (including TEP, TEF, TEC, TES, TEB, RHN, and PNN) are to be removed from the timber base. Once the

District makes and approves the choices necessary for the issues defining the alternatives, a special OUT theme is sent to the Oregon State Office.

Step 2: Once the selections are made, the determination of the intensive timber inventory can be completed in WODDB through the use of Command Programming Language (CPL) software in PRIMOS and MOSS/MAPS. Automating the processes is necessary since much of the data has been recorded for individual townships (approximately 36 square miles) and there are over 400 townships in WODDB. The township level themes were recorded at a 1:4800 scale.

Step 3: After the Districts have identified locations designated for special protection and the other spatial restrictions have been calculated in MOSS/MAPS, WODDB is also used to generate interim files and plots depicting the inventory remaining in the timber base. District personnel use the District-wide plots to aid them in their selection of stands to be protected under Issue Numbers 2 and 3, Old-Growth Forests and Habitat Diversity. The completion of this final land-use issue will directly determine the available inventory in the Mini-MicroStorms database for the TRIM+ model formulation. A special Old-Growth Block Theme will be created from the District's selection process and added to the WODDB to facilitate future analyses and report generation.

The following sections outline the procedures which will be used to define the **Active Forest Inventory** for each of the Alternatives, separately. The steps which are predicated on having Districts involvement in the decision process will be highlighted.

Automated Analyses

Roads, power lines, railroad beds, as well as all roads built for interim timber sales between 1988 to 1990 are to be buffered to a 45-foot width. Non-forest locations are also identified and removed. Issue Number 1 indicates that all forest lands be allocated to timber production consistent with the management direction for other resources, except for the following timber productivity classes including NonSuitable Woodland, Suitable Woodland - low site, and Suitable Woodland - NonSuitable Commercial Forest land.

Issues Numbers7 and 8 establish Riparian Management Areas (RMAs) on perennial streams, generally 3rd order or larger, lakes, ponds, and other waters, to meet Oregon Forest Practices Act requirements and Oregon water quality standards. Within RMAs no lands would be considered 'available' (to offer timber for sale as part of the allowable sale quantity). Buffered RMAs for the Upper Willamette SYU are calculated in WODDB following the following directions:

Stream Class	Single line	Double Line
3	08.0 F	105 F
4	155.5 F	150 F
5	220.5 F	210 F
6+	259.0 F	240 F

Lakes - 150 F

The difference between single and double line streams is simply that the latter were recorded by identifying the banks of the river or stream rather than simply the centerline of the feature. These calculations are all conducted automatically in the WODDB, but the remaining procedures require human-based decision-making.

District Input

As explained above, the OUT theme is to be created before the MOSS/MAPS macros are used to create the vector and raster files necessary for completing the MOSS/RMP Issues 2 and 3 phase. District personnel are to identify the following features for each township with a selected polygon, for any that may exist:

Issue Number 4 - Protect habitats of Federal Candidate, State Listed and Bureau Sensitive Species **to the full extent on public domain land**, and protect habitats of Federal Candidate species known only to occur on BLM-administered lands to the extent considered necessary to prevent their federal listing.

Issue Number 5 - Retain all existing ACECs and RNAs. Designate potential ACECs and RNAs that meet criteria only if the relevant values are not protected by other authorities.

Issue Number 9 - Continue management of all existing high-use recreation sites and trails and consider re-opening sites closed in recent years. Retain options for new high value potential recreation sites and trails.

Issue Number 9A - River segments eligible for scenic river status found suitable for designation consistent with their highest potential classification, and river segments eligible for wild classification found suitable for designation as scenic, if all of the following circumstances exist. If only the economic impact test is not met, find suitable for designation as recreation.

- no net adverse economic impacts on the local economy,
- river segment possesses at least one outstandingly remarkable value for which it is considered by BLM to be among the top two rivers in the SCORP region,
- BLM can effectively manage the outstanding values of the river segment.

Once the final District calls are made and approved, the WODDB can generate acreage estimates for every Operational Inventory Unit and the land use types which can be assigned within the unit's boundaries. The following list represents the hierarchy used to identify the types of features which will impact the availability of sites relative to this alternative for the harvest model formulation. Items at the top of the list are removed first and are counted first versus those items identified lower in the hierarchy.

Road
Nonforest
Nonsuitable Woodland
Suitable Woodland - Low Site
Suitable Woodland - NonCommercial Forest Land
OUT - REC, SRD, & VRM1
Threatened & Endangered Species Habitat
Riparian Management Areas
Buffered sites of REC, SRD, SSW, & SFH; Intersected with VRM, as well as viewshed with better than 50 percent BLM lands.
1989 and 1990 Interim Timber Sales

Automated Analysis

The final MOSS/MAPS analysis cannot be generated until all OUT Theme selections are identified, since Issue Number 6 requires an intersection between the VRM theme all land designated for VRM II Management which exist in a viewshed where BLM administers at least 50% of the area, and all sites within 1/4 mile of developed recreation sites, state and federal highways, state scenic waterways, and rivers designated under the Federal Wild and Scenic Rivers Act and which are inventoried for VRM Class II Management.

The remaining timber land is considered available inventory for the harvest scheduling model. However, CUT (FY '90 sales) and PLANTED (FY '89 Sales) sites will be noted and their inventory volume reduced appropriately. In the Eugene District, sales which were thinned in FY '89 or '90 are to be identified separately. Finally, in the Medford District, all FY '89 or '90 sales harvested as Shelterwood, Thinning, Mortality Salvage, or Seed Tree Removal are to be identified separately.

District Input

After the OUT Theme is created and the WODDB macros are used to determine the inventory subdivisions, the District personnel will create the theme of 'Picked Blocks' of old-growth stands in order to complete Issue Numbers 2 and 3. The **Guidance** states that this alternative should provide for intensive management of wildlife habitat and maintenance of biological diversity. It should strive to attain a balance of forest serial stages and associated plant and animal communities. Varying sized blocks of mature and old-growth forests would be spatially distributed over BLM-administered land, focusing on serial protection of identified areas where special plants and animals cluster.

Each District is to be provided with Resource Area Plots indicating the following items:

Nonforest
Nonsuitable Woodland
Suitable Woodland - Low Site
Suitable Woodland - NonSuitable Commercial Forest land
Riparian Management Areas
T&E species recovery areas where timber harvest is prohibited, plot file AE6
Special Areas/Wilderness Areas
Public Domain Lands
Sites under VRM Class I Management - out of base
Sites under VRM Class II Management - extended rotation

The twin concepts of Biodiversity and Gap Analysis will be used to aid district personnel in the determination of which blocks of old-growth should be marked for protective management. Once all three steps are completed, the remaining inventory is ready to be loaded into the harvest scheduling model.

Harvest Model Linkage

Once the land base available for timber management has been defined, the acreage data is downloaded to the PC Database Micro*STORMS, a Revelation-based stand inventory database. The same attributes tied to the Operations Inventory (OI) and Timber Production Capabilities Classification (TPCC) themes in WODDB are also identified in this relational database. The ORACLE database software on the Bureau's Prime computer is used as a bridge between the MOSS/MAPS software and the Micro*STORMS database. The linkage between these this software is accomplished via ASCII file data transfers.

Table 1 presents a listing from the OI units in Township 17S-03E, Section 7, Upper Willamette SYU, for Alternative A. The table demonstrates that the total acreage within an OI unit polygon can be represented by a number of different land use categories. Keying on each stand's attributes and net available acreage, the inventory files can be prepared for the Timber Resource Inventory Model Plus Harvest Scheduling (TRIM Plus) by Resources Economics International.

TRIM Plus allows users to allocate individual OI units and their available inventory to Basic Resource Unit (BRUs) files which are the smallest unit of timberland that has been identified as being a particular type of existing forest stand based on inventory sampling and database information. The Bureau has assigned OI units to individual BRUs based on the stand's major species type, past management (or lack thereof), and expected productivity responsiveness to silvicultural activities. Stands with different ages but with the same past history are combined into a BRU. The inventory specialist on the Eugene District separated the inventory into only five BRU types, (1) well to overstocked Douglas fir stands, (2) minimally to understocked Douglas fir stands, (3) natural stands commercially thinned at age 50, (4) natural stands commercially thinned at age 60, and (5) hardwood stands which could be converted to Douglas fir.

For each BRU file, a companion file called the Grouped Resource Unit (GRU) is also created. THE GRU file represents a collection of current and future management instructions and data sources used by the modeler for influencing the manner in which the stands within the BRU

OI Unit	Gross	Road	Nonforest	Nonsuitable	Suitable	Riparian	89 Sale	Net
813917	237.7	0.5			9.4	30.9	1.1	195.8
811440	11.6	0.7						10.9
811441	134.4	6.2			1.7	3.9	10.9	111.8
811435	7.9	0.0	7.9					0.0
812424	25.8	0.3				0.1		25.4
811437	61.6	2.4			7.9	2.3	8.5	40.6
811438	109.5	4.2		0.7				104.6
811439	37.4	1.5				0.4	2.9	32.6
814007	1.7	0.0			1.7			0.0
Total	627.6	15.8	7.9	0.7	20.7	37.6	23.3	521.6

Table 1: Township 17S-03E Section 7 - Acreage Hierarchy

are, to be managed throughout the simulation. The information included in a SYUs set of BRUs and GRUs will determine the Allowable Sale Quantity for the next decade. The beginning inventory in the BRUs, the definition of the BRUs, and the instructions included in the correlated GRUs can vary by SYU and District to better model growing conditions and expected management.

10 Year Scenario: Tying the Harvest to Reality

Once the allowable sale quantity is determined for an SYU, the environmental impact of implementing that level of harvest over the next decade must be determined. The output from the TRIM Plus model identifies the number of acres to be harvested during the next decade by age-class within each BRU. Since the Micro*STORMS database relates which OI units belong to which BRU/age-classes, it would initially appear fairly simple to relate the harvest level calculated in the model to actual harvest sites in the forest. However, the geographic size and shapes of the OI units where designed to capture distinct stands by forest type. They do not naturally correspond to the engineering design layout for most of the sale units offered to the public via the bid system used by Federal Agencies in the Pacific Northwest. A completely new theme was created during the winter of 1988-89 for the express purpose of creating sale unit polygons for all merchantable timber lands on the Bureau's lands in Western Oregon.

The Representative Timber Sale Unit (RTU) theme was not only consolidated into WODDB, but the subject names for all such entities are fully integrated within the Micro*-STORMS database files for each OI unit. Table 2 demonstrates that for any representative timber sale unit or representative timber sale unit road that may exist in an OI unit, the acreage is identified, net of all factors which remove land from the base. This theme supplies the remaining link for relating the expected harvest level to timber sale sites which will have an impact on important environmental issues. TRIM Plus cannot request for harvest any more acres than were made available to a particular BRU/age-class, and the linkage in Micro*STORMS of OI units and RTU allow the districts to select a subset of sale units which will satisfy the harvest requirement in the model.

It is important to note that in the past, harvest scheduling-based planning analyses normally estimated the level of allowable cut that could be sustained and the field offices simply used these figures as 'hunting licenses'. Typically, once the district knew the harvest level assigned to their administrative unit, foresters searched for the stands which would provide the most volume for the easiest/closest/most cost-effective sale possible. Since the forests in the Pacific Northwest were initially unmanaged, this approach worked fairly well. However, the world of public forest management has changed significantly in the past decade. The conversion of the natural forest ecosystems to a managed forest system is nearly complete. It has even changed direction here in the Pacific Northwest; not only are spatial issues now much more important, but the timing of silvicultural treatments and final harvest have become even more critical inthe determination of the highest sustainable harvest level.

The harvest scheduling model formulation used applies different levels of productivity to each different BRU and corresponding age-class via the instructions included in the GRU files. The harvest scheduling model determines the upper limit on the next decade's allowable sale quantity, based on harvesting specific types of forest stands. The foresters must attempt to find and harvest such sites during the implementation of the approved RMP. The creation of the RTU and RTR Theme, as well as the planning and methodology developed by the 10 Year Scenario Team have

OI Unit	TRS	Stand Description	Age	BRU	RTU	RTU.AC
811435	17S-03E-07	NR		321130	S17E03_0704 <-	0.3
					S17E03_0611	0.2
811437	17S-03E-07	ZZ D4-=1880	110	231115	S17E03_RTR_26	0.7
					S17E03_0610	6.2
					S17E03_0611	1.0
					S17E03_0703	27.9
					S17E03_0704 <-	11.9
					S17E03_0806	0.1
811438	17S-03E-07	ZZ D3-=1925	60	231115	S17E03_0608	5.1
					S17E03_0701	41.9
					S17E03_0609	18.2
					S17E03_0703	1.5
					S17E03-0702	36.8
811439	17S-03E-07	ZZ D3HD-=1920	70	231115	S17E03_0708	13.2
					S1703-0707	16.9
					S17E03_0706	0.2
					S17E02_1220	1.6
811440	17S-03E-07	N D2HD-=1940	50	231115	S17E02_1220	8.7
					S17E02_1201	2.0
811441	17S-03E-07	ZZ D300-=1920	70	231115	S17E03_0711	17.9
					S17E03_0710	34.2
					S17E03_RTR_82	0.7
					S17E03_0704 <-	18.9
					S17E03_0817	9.4
					S17E03_0807	23.4
					S17E03_0712	6.8
812424	17S-03E-07	X	0	231140	S17E03_0710	0.3
					S17E03-0712	0.4
					S17E03_RTR_81	0.4
					S17E03_0817	0.1

Table 2: Operations Inventory File

been with the express purpose of providing a successful link between the predictions made by the harvest scheduling model and the activities which would occur in the districts during the next decade. The work provides a mechanism for evaluating the impact of each alternative in each SYU on the specific spatial characteristics within the forest ecosystem. In the following paragraphs we will outline the procedures developed to provide a mechanism for assigning individual sale units to the those required to meet the harvest level calculated for each set of alternatives and SYUs.

Once the SYU's harvest level for the next decade has been determined by the TRIM Plus model formulation, the task of selecting which sale units are to harvested begins. The Micro*STORMS database is used to identify all of the eligible sale units. Eligibility is determined by whether the sale unit is dominated by a BRU/age-class which the model indicated should be harvested. Table 3 lists all of the potential sale units which reside wholly or in part in Section 7 of Township 17S - 03E.

The RTU S17E03_0704 actually overlaps into parts of five Operational Inventory Units. Since the largest acreage in this unit belongs to two OI units which are assigned to the same BRU and age-class, BRU 231115/age class 70, then this unit is identified as a complex sale unit for BRU(23115) and age class (70). the unit is labeled complex since if the unit is selected more than one BRU/age-class will have acreage harvested. This potential sale unit is eligible for selection if the model determined that acreage of this type should be harvested and regenerated during the first decade.

RTU Unit	OI Unit	BRU	Age	RTU.AC	Dominant OI	Dominant Age
S17E03_0701	811430	231115	60	2.0	231115	60
	811438	231115	60	41.9		
	811426	231115	90	0.3		
	813917	231115	110	0.1		
				44.3		
S17E03_0710	812424	231140	0	0.3	231115	70
	811441	231115	70	34.2		
	813917	231115	110	4.7		
				39.2		
S17E03_0704	811445	231115	60	0.1	231115	70
	811444	231115	70	13.7		
	811437	231115	110	11.9		
	811435	231130		0.3		
	811441	231115	70	18.9		
				44.9		
S17E03_0707	811439	231115	70	16.9	231115	70
	813917	231115	110	14.9		
				31.8		
S17E03_0713	811462	231115	110	1.0	231115	110
	813917	231115	110	19.0		
				20.0		

Table 3: Representative Timber Sale Unit File

The RTU S17E03_0713 represents an example of a discrete sale unit. The unit is referred to as discrete since the two OI units which partially fall within the sale unit, both belong to the same BRU (23125) and age class (110). As far as the model is concerned, selection of this sale unit will only contribute to meeting the harvest requirements of this BRU/age-class. Conversely, the selection of any complex sale unit results in additional acres harvest other than for the BRU/age-class desired.

If the harvest scheduling model indicates that 30% of the acreage in any given BRU/age-class should be harvested during the next decade, this would imply that there are more potential sale units available to select from than are actually required to mimic the calculations in the model. Since the harvest scheduling model does not know or care where any particular potential timber sale resides, it is up to the actual selection process used to determine which units from where should be selected.

The selection process utilizes an algorithm based on the macro-command language of the Revelation database software. The algorithm begins with the oldest age-class in a BRU and attempts to meet the harvest level requested. For each BRU/age-class, the algorithm randomly selects both complex and discrete potential sale units until the number of acres selected matches that of the harvest model. The selection process is random in terms of unit size, location, or whether it is a discrete or complex RTU. Discussions with foresters involved with District timber sales indicated that the selection procedure results in a set of sale units which fairly represent reality.

As the algorithm works through the age-classes within a BRU, the solution set for an age-class will include complex sale units which incorporate acreage of other BRU/age-classes. The algorithm accounts for this 'complex acreage' already accumulated as the procedure works through all BRU/age-classes which the model indicated should have acreage harvested. Harvest acreage totals are maintained and updated as new units are selected. This, after all, represents the primary strength of a database software program.

Once all of the eligible BRU/age-classes have had sale units assigned, one of several conditions may exist. First, if the BRU/age-class was to be completely harvested, the total set of eligible sale units may not equal the acreage indicated in the harvest model's original inventory. This result could be expected since some small pieces of each BRU/age-class will be included in potential sale units which are not desirable for the current harvest. An example of this would be the case where a potential sale unit may be designed where the unit is 35 acres of 50-year old timber with a 5 acre strip of 150-year old timber along one side of the unit. The combination of timber stand ages may make good sense from the stand point of the engineering layout of the unit. However, it does not make sense to pick 35 acres of a forest type not desired only to obtain an additional five acres of the 150-year old material needed to completely meet the computations of the harvest scheduling model. Representative timber sale units could be subdivided into small fragments by the spatially-oriented land uses highlighted in the **State Guidance** alternatives. Such small pieces of timber sales, less than five acres, are also ignored by the selection algorithm and could cause the algorithm to fail in finding all the sale unit acreage indicated in the harvest scheduling model. When this case occurs, no additional acreage can be selected but the quantity of timber harvest missing can be determined.

In the second case, a BRU\age-class that should be partially harvested may actually end up with more than the average requested. If the difference is smaller than the size of the smallest selected discrete sale unit, the set of selected unit remains and the overproduction of timber volume is calculated. Otherwise the excess acreage is reduced by the removal of one or several discrete sale units of the approximate acreage required to bring it into balance.

With the third case, an BRU/age-class may have acreage selected for harvest when the model indicated that the entire acreage should be left to grow and be harvested in a latter decade. This has been a minor problem and has been handled in one of two fashions. If the quantity taken is substantial, then attempts are made to replace the complex sale units involved with other units in the BRU/age-class. The macro-command language can be modified to consider this problem. If the quantity selected is minor, than the resulting timber volume is applied toward the overall decade's total harvest. This volume provides a counter-balance to the under-achievement of harvest volume in the first case mentioned above.

Once the sale units are selected, the required road network necessary to gain access to the units must be identified. The same forest engineers who created the polygons of the potential sale units also mapped out the additional roads which would be required. However, the MOSS/MAPS GIS software does not have the capability of recognizing the adjacency of features in the geographical space. Therefore, we developed a mechanical process to determine which roads need to be added to complete the identification of the next decade's timber program. District analysts can complete the road network identification process in a day for an entire SYU. Since BLM-administered lands are already substantially roaded after 40 years of timber sales, the existing checker-board distribution is intermingled with private timber lands.

Several examples of potential road segments are listed with the potential sale units in Table 2. As the district analysts determine which road segments are needed, they can be identified in the Micro*Storms database and the acreage added to the running totals. Once all these steps are completed, any minor discrepancies can be rectified by modifying the solution slightly via additional analysis with the database.

With the completion of the selection of all the sale units and road segments for an Alternative/SYU, a theme in the WODDB can be created for further analysis of environmental effects. This new theme can be incorporated in an analysis of the impact of clearcuts on the water quality for all watersheds in the SYU. Additionally, the impact of the clearcuts can also be included into a model predicting the survivability of the Northern Spotted Owl.

Summary

The methodology outlined for defining the alternatives only provides a limited review of all the possible sets of land-use classifications. It is meant to demonstrate a wide range of potentialities and opportunities. Each District will have an opportunity to craft a 'preferred' alternative based on the lessons learned. Additional comments from the public, as part of the review process, also provide a possibility for further enhancements. The Bureau has chosen a methodology which will not find the 'optimal' solution for determining the 'best' manner for managing the public's natural resources. However, it has the capability of working toward a compromise where the interested parties can consider the trade-offs involved.

The methodology developed and outlined in this paper is not elegant, but it does work. More importantly, it is simple enough that it is being used by District inventory specialists, foresters, GIS specialists, and planners, rather than being completed by support staff in the State Office. With six Districts and at least five alternatives, this is a task which needs to be distributed. It allows the State support staff to do just what it is supposed to do; support the efforts of the Districts while they develop their RMPs. Additionally, several points need to be remembered.

First, the solution set of sale units and road segments only represents an estimate of which units will actually be harvested during the next decade. As we move forward in time, things change; forest fires, diseases, and insects affect forest growth and yield. Future changes in landuse classifications will also impact where timber will actually be harvested in the future. This analysis provides an important 'what if' for incorporation into the formal planning process and comparison of alternatives.

Second, the spatial distribution of the selected sale units and road segments may cause undue negative environmental impacts in certain locations. Time does not allow the Districts to modify their solutions. When we finally develop the 'preferred' alternative for each District, there may then be time to adjust the model. This may require reducing the availability of the timber inventory in some locations for a decade or two, thereby lowering the overall sustainable harvest for the SYU.

Third, the linkage of actual sale units to the harvest scheduling model does not complete the analysis. Once the spatial distribution of timber sales are known, other models can be utilized to evaluate their impact on a range of environmental issues. Currently the topics of greatest concern include analyzing the impacts of the alternative on watershed water quality and Northern Spotted Owl survival.

Finally, this methodology does not represent the manner in which harvest scheduling models should be linked to a land information system. Eventually, the harvest model must cease to be two-dimensional, i.e., volume productivity versus timing. We must develop a three-dimensional model where spatial location can be incorporated into the analysis. Such a system will allow analysts to focus on timber productivity while enhancing or reducing the impact on other forest systems.

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Modeling the Visual Impact of Forest Harvesting: an Integrated Approach

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Abstract

Foresters are under increasing pressure to minimize the visual impact of forest harvesting operations by selecting optimal size, orientation, positioning, and sequence of roads and cutting areas, as well as by adopting selective logging techniques. The manual techniques of sketch mapping and photograph retouching used to illustrate visual impact are now being augmented, or even replaced, by using a geographic information system to combine and display forest cover and topographic data. The primary advantages of this new methodology are its speed, low cost, and lack of human bias in its operation; the disadvantages are the relatively simplistic images produced to date. New technology, first used for special effects in cinematic production, permits controlling not only the texture of the landscape but also atmospheric phenomena and lighting. This paper presents a case study involving these issues.

Concurrent Session 8

Environmental Issues - Multiple Use

Sampling the Countryside of Great Britain - GIS for the Detection and Prediction of Rural Change

Oil and Gas Well Drill Site Location Analysis in the Targhee National Forest, Idaho, Using a GIS

GIS and Sustainable Development in Forest Management

The Application of a GIS for Optimizing Multiple Land Uses

GIS'91

Symposium

Vancouver
British
Columbia
February 1991

Sampling the Countryside of Great Britain:GIS for the Detection and Prediction of Rural Change.

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Abstract

In 1990, the Institute of Terrestrial Ecology completed a survey of the land use and vegetation of Great Britain (GB), repeating and extending the earlier surveys of 1978 and 1984. The surveys, which were structured using the ITE Land Classification, were funded by Government departments and the information collected is being used to assist in central decision making. GIS is being used at several different levels: checking information recorded in the field; incorporating remotely sensed imagery; comparing individual survey sites; linking other census; and surveyed information and presenting the results. The survey uses the Ordnance Survey of GB (OS) 1 km square grid, and collects information on all types of land use. The three dominant forms of land use, agriculture, forestry and urban, are recorded in formats which are as compatible as possible with those used by other specialist organizations (e.g., Forestry Commission, Ministry of Agriculture, Food and Fisheries (MAFF) and Department of the Environment), which allows information collected by different groups to be integrated and data to be exported in accepted styles. The scale selected has proven successful for use at both regional and national levels. The Land Use Research Group at Merlewood has a working knowledge of the requirements of policy advisers and can present ecological information in a variety of relevant ways. Maps and summary statistics are easily produced but estimates of accuracy can raise doubts and lead to results being unfairly undervalued. It is important that GIS is not seen as a system which can only give absolute answers; it must be able to qualify its boundaries and statistics in a comprehensible way. There are a number of statistical methods which can be applied to land cover data, but the presentation of the cartographic results is always the most problematic aspect. The limits of the production and interpretation of error terms are described, detailing elements which are assessed and those which are omitted.

The surveys are a good example of a practical way of collecting and passing information between a variety of sources and disciplines. Results and methods of presentation are discussed.

Introduction

Objective information describing the environment is extremely valuable for assessing the consequences of changes in government policy affecting the countryside. However, the level of detail required in order to make an ecological assessment of the consequences of change, along with the lack of a rigourous set of ecological theories, make it difficult to provide a flexible system capable of supplying both comprehensive and comprehensible information. Decisions and policies at a national level are made by intelligent people who look for assistance and information from specialist groups and organizations. Some of these groups are large and capable of producing detailed census information covering extensive areas. Examples of these in Great Britain (GB) include government offices such as the Ministry of Agriculture, Fisheries and Food and the Forestry Commission.

However, ecological information is different from other measures of land use; rarity of species and habitats is commonly seen as a virtue, and community composition is complex and extremely variable. Ecological information has often been presented to decision makers as expert opinion, which may be difficult to evaluate. An objective, relatively low cost technique is needed to monitor the ecological status of the rural environment. To be of use to policy advisers at national and regional levels the system must be capable of spatial analysis and being linked to other more extensive datasets.

The Institute of Terrestrial Ecology has devised such a monitoring system (Bunce and Heal, 1984 and Howard and Bunce, 1989) and is surveying both the ecology and land use of GB on a regular 6-year cycle starting in 1978.

Applications of GIS

Different functions of GIS are being applied within the survey for different reasons. The survey sites, 512-1 km squares drawn at random from a stratified grid (Figure 1), were mapped in the field for all land cover features. The surveyors used the OS 1:10 000 scale maps as a base map for recording, but these were updated by interpretation of recent aerial photography. Every parcel of land within the sample squares was visited on the ground and the land cover was recorded along with the details of the boundaries. The plant species were recorded wherever they exceed 25%; in trials, attempts to record in more detail were found to be too time-consuming. The positions of isolated individual trees were also recorded from the aerial photographs and their species were determined during the field survey. The land cover parcels were recorded as distinct features if they were larger than 20m^2. otherwise, they are recorded as mosaics, automatically producing a limit to the recording of certain features. Linear features including hedgerows and field headlands, were also recorded.

The information was recorded in the field onto five distinct maps:

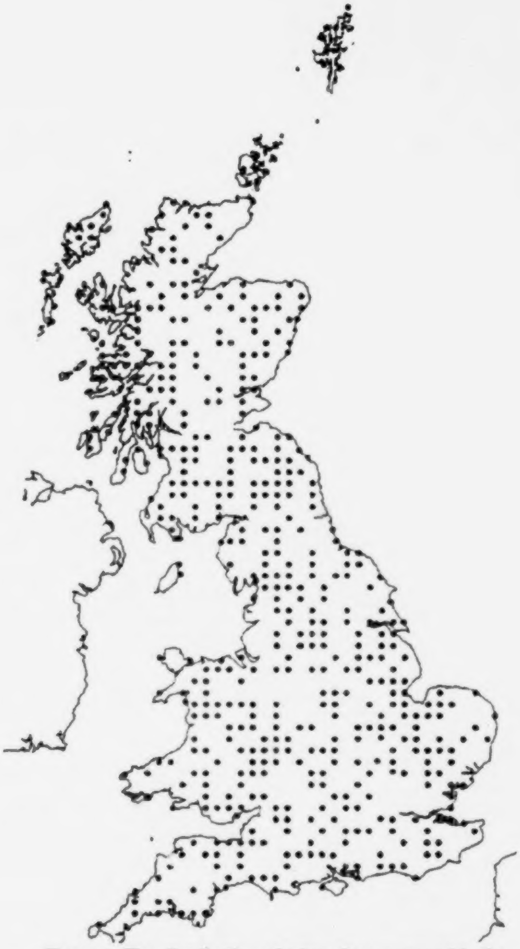

Figure 1. The distribution of 1 km sites surveyed in the Countryside survey of 1990.

1. physiography;
2. agriculture and natural vegetation;
3. forestry;
4. boundaries; and,
5. structures and communications.

The information is being digitised and stored in ARC/Info, so that it can be combined with information from the 1978 and 1984 surveys; this makes comparisons between years for the same sites relatively straight forward. Considerable care is being taken to ensure that the ARC coverages only show changes that were recorded in the field. For lowland sites, the process is straightforward, in that field boundaries are usually mapped on the OS base map, so making a copy which is updated by re-labelling is safer than digitizing twice (Figure 2). However, sites in the uplands, where boundaries are less distinct, can cause more of a problem. Frequently, surveyors have had to define the boundaries of parcels in

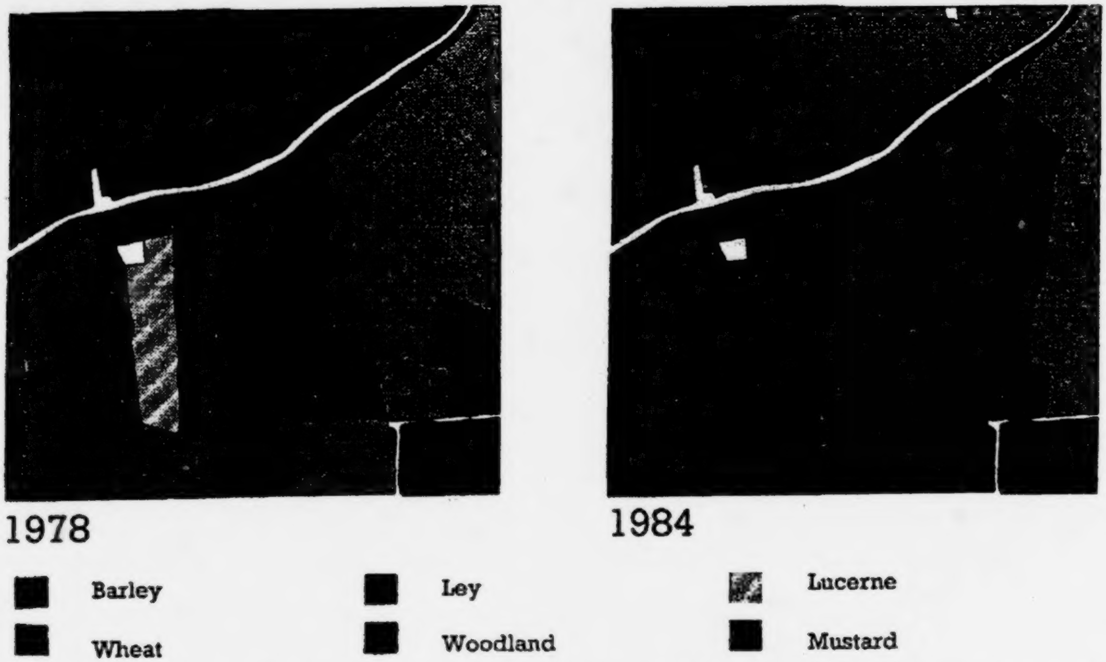

Figure 2. The agricultural and forestry land cover in a single surveyed square in 1978 and 1984. The size, shape and position of the parcels remains constant although the land cover within them may alter.

the field. The 1990 survey has been the first to make use of aerial photographs to help define boundaries, making the mapping more accurate. Judgment has to be used when digitizing to distinguish between real changes and recorder differences. Where the parcels differ, the 1990 result is considered to be more accurate, and is used when the boundaries almost coincide (Figure 3).

Another problem with the boundaries, especially in the more open uplands, are the changes which occur at a boundary. In an arable environment, the fence line may be a sharp boundary between two different crops, but on a moor, identifiable vegetation groups may merge continuously, leaving the surveyor an awkward decision as to where to draw a boundary. To represent the boundary in a GIS as a distinct line is both misleading and incorrect. A number of methods can be used to circumvent the problem, including contouring the densities of habitat types. ITE is investigating the application of fuzzy logic (Chang and Burrough, 1987) to present such boundaries. Although ARC/Info is designed to present crisp boundaries, it is possible to include probablistic information to present parcels as part of a continuum (Wang et al., 1990).

To increase the precision of recording of botanical features, a number of quadrats were recorded in each sample square. Three different styles were used:

1. nested quadrats of 200m^2 (Bunce and Shaw, 1973), which were randomly placed throughout the 1 km square and the plant presence and cover recorded;
2. linear quadrats of 1m x 10 m, which were positioned along hedgerows, streamsides, roadside verges and boundaries; and
3. 4m^2 quadrats, which were positioned in additional semi-natural habitats not sampled by the random nested quadrats.

The smaller quadrats and the centre of the nested quadrats can related to the National Vegetation Classification (Rodwell, in press) as used by the Nature Conservancy Council, allowing predictions of national coverage of the types to be made. The sites of all of the quadrats have been mapped and permanently marked with metal plates so that they can be relocated during future surveys. The information recorded in the quadrats can be spatially related to the mapped information, allowing the interpretation of the relative changes in both land use and vegetation. The quadrat information will also be related to soil information, which was collected by field surveyors in 1978 and updated through a contemporary survey of the same sites carried out by the Soil Survey and Land Resource Centre for England and Wales and the Macaulay Land Use Research Institute in Scotland. One of the benefits of collaborative research with leading organizations is that information is collected and presented using methods and terminology which are commonly used, consistent and widely understood.

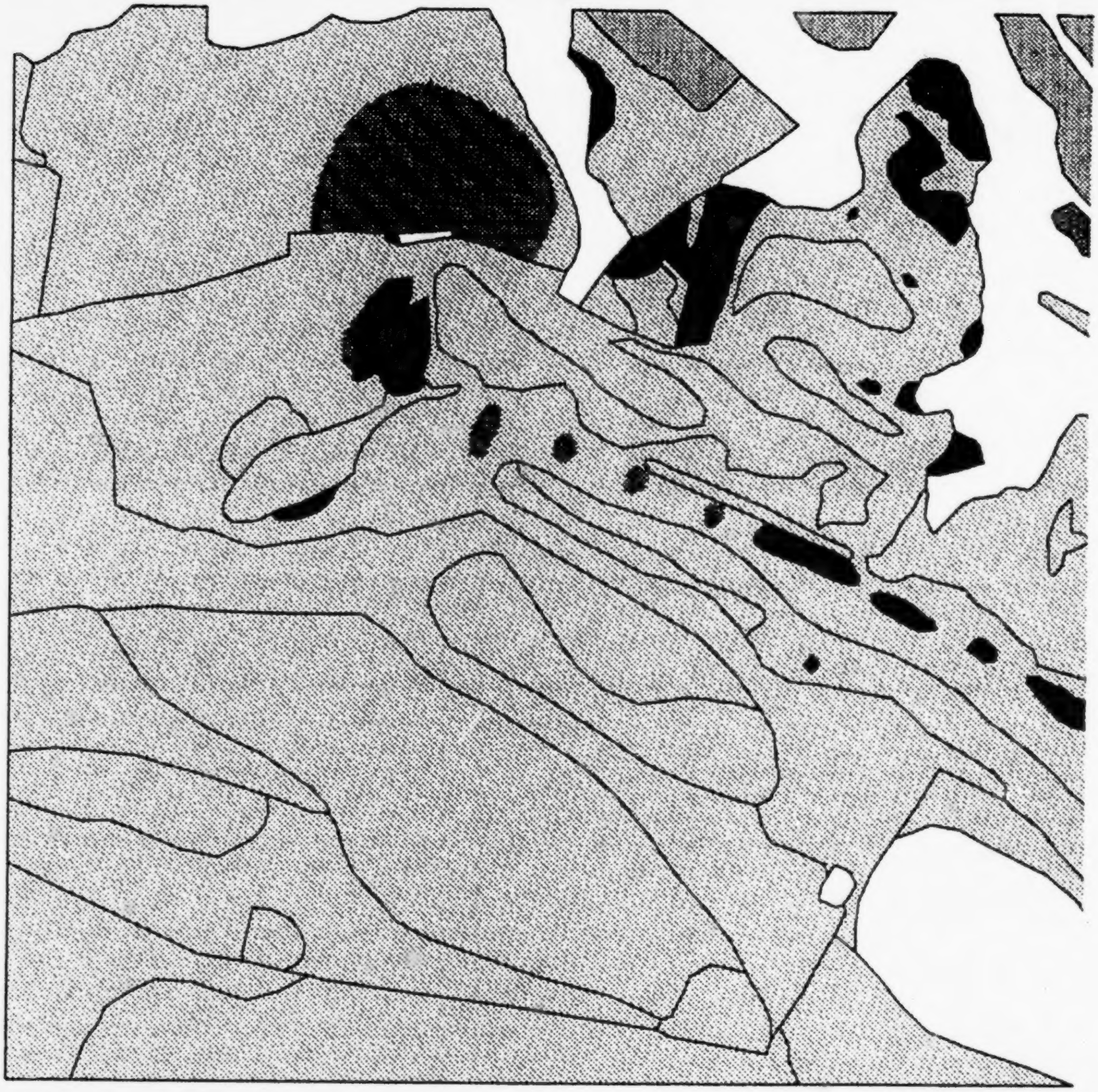

Figure 3. The agricultural land cover of an upland square. The cover categories are divided into three broad types, although the divisions (recorded in 1990) within those types are indicated. The darker shaded areas show parcels of bracken in 1978 and 1990, some of the parcels remain relatively constant while others appear in only one or other survey. The boundaries of the broader categories are more stable between years.

Definitions

Terminology and definitions can cause problems when working in a multi-discipline project with a number of different organizations. The difficulties only rarely occur at levels of fine detail, but are usually associated with broad definitions. It is essential that accurate descriptions of the terms used to identify parcels are presented with any results but most individuals and groups consider that they understand broad terms. For example, even a common English dictionary includes three different definitions of 'forestry'; land set apart for hunting; a tract of wooded, uncultivated land; and a stretch of land once wooded (Irvine, 1972). The Forestry Commission usually records commercial woodland, ignoring scrub woodland, small copses and scattered trees. However, within their commercial woodland are included rides and clearings. Although other groups also refer to forestry with different definitions (e.g., Monitoring Landscape Change (MLC) and MAFF), their results are usually compared directly without performing the necessary checks for compatibility (Bunce, 1990). The danger is that estimates of area and extent are rarely questioned if the numeric values are approximately the same. Similar problems are found with other broad definitions such as road areas, agricultural land and physical features. In a different context, the problem has even led to proposals that terms used in everyday speech should be avoided. Birch, (1957), proposed that the biological term 'competition' should be abolished since there was no single definition.

Estimates of Error

Although information is recorded about individual sites, the method of presentation is in the form of predictions for land cover and vegetation, either nationally or for large regions. For each feature, the figure is produced by multiplying the mean area per 1 km square for each sample strata, by the known number of squares in that strata, and then summing the strata totals. The sample size is small, 512 in 247 000 or 0.2% of GB, and it would be desirable to increase the size, but, as the sample is based on a grid, the coverage is more evenly dispersed than a simple random sample (SRS), or even a simple stratified sample. Compared to other uses of stratified sampling of populations, eg opinion polls (c. 1000 in 56 000 000 or 0.001%), the sample seems moderately large and has the benefit of the field survey being completed in a short time span (c. 4 months).

It is essential to know the precision attached to any estimates of land use coverage and this can be achieved by calculating error terms. For any given survey design, the methods of calculation are well known (Cochran, 1977). The interpretation of error terms, in whatever form they are expressed, is complicated, especially where the distribution of the variables diverges from normality. Biological factors, especially when rare or managed, frequently show non-normal distributions. Heather is almost bimodal in its distribution both within and between sample strata; it occurs frequently in some land classes but is totally absent from others. Even in the 1 km squares of those land classes where it is found, heather either tends to occur as large blocks or is absent. In such cases, the mean and its standard error do not necessarily represent accurate confidence limits for the land use, although the problem diminishes as the sample size increases. Despite the limitations of the equations, some measure of the standard error of the estimates should be given.

Once calculated, there may be difficulties in presenting error terms; for tabular and graphical data there are a number of standard formats but cartographic results are usually handled with crisp logic. Even statistical cartography does not concentrate on confidence values (Dickinson, 1973). The lack of a standard method of expression causes problems in interpretation as the information is either complex or easily misunderstood. It is tempting to ignore error terms, even when they have been calculated, rather than to educate the audience. To interpret the error terms, it is necessary to understand the methods used to collect the information and to appreciate the assumptions on which they are based. The standard errors for the ITE land cover features surveyed in 1978 have been calculated and compared with the predicted random distribution, derived from the formula presented by Cochran (1977). The application of the stratification showed an improvement over SRS in only 30% of the cases, because of departures from the optimal sampling of the strata (e.g., sampling more in proportion to the area and variation of the strata). It has been calculated that if the sampling had been optimal, then 90% of the features would have had smaller error terms, indicating that the stratification itself was successful for most land cover features. Recent surveys have sampled the strata in proportion to their area, which increases the efficiency for estimation of population totals.

For the estimation of the errors attached to change, there are two general strategic approaches: to measure the same areas on successive occasions, and to carry out separate random samples and detect change from differences between the population means. In the former procedure, as adopted in the current project, any changes detected are certain to have taken place, and the error terms attached to them will relate to the consistency in the size of the change concerned. In the second procedure, the variability within the sample populations on each occasion may be so high that valid change cannot be detected. In the ITE surveys, the 8-1 km squares per strata surveyed in 1978 were resurveyed in 1984, with 3 exceptions, along with 4 extra squares in each strata. Change was estimated in two ways:

1. Comparison of the population estimates (256 squares in 1978 with 384 squares in 1984 and 512 squares in 1990). The standard error of these estimates involve the correlation between the land cover values in the three surveys. A positive correlation means that squares are more likely to have similar values in the surveys.

2. Comparison of changes in individual sites. If the correlation between the values on the two occasions is sufficiently high, greater than 0.85, in enough strata, then it may be more precise to estimate change simply from the squares surveyed twice, ignoring the extra squares surveyed only on the second survey.

An example of these results is the change in wheat between 1978 and 1984 (Barr et al, 1986). The two estimates of change differ, depending upon the number of samples used from the 1984 survey. If only the squares visited on both occasions (8 per land class) are used, the change is an increase of 732 332 ha, with a standard error of 27.47%. If all the information from the 1984 survey is used, the increase is estimated as 885 910 ha, with two estimates for the standard error. If the samples are handled as two distinct populations, the standard error is 27.84%, compared with 21.81% if the covariance for repeated samples is included. The relationship between the size of the estimated standard errors depends on the size of the change. In conclusion, standard errors are a useful measure of the precision of estimates. Although the mean values will not change significantly, the stratification would produce reductions in the standard error if the sample size was increased, or if the sample was proportional to the areas of the strata.

Summary

Practical difficulties and expense prevent ecologists collecting large census datasets, and historically, the sampling techniques and methods of analysis have evolved to produce efficient systems. The data has a strong spatial element, and is capable of analysis and presentation using GIS techniques, but the style of data requires developments and extensions of the existing methodologies. Particular care should be given to comparisons of statistics from different surveys, especially in relation to the definitions of individual surveyed features. Presentations of error statistics should be accompanied by full and thorough descriptions of methods used.

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Oil and Gas Well Drill Site Location Analysis in the Targhee National Forest, Idaho, Using a Geographic Information System.

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Abstract

The inherent spatial character and distribution of non-renewable resources make their associated locational data amenable to incorporation into a GIS. The use of a computerized, interactive GIS to manage large and diverse data sets can enhance the probability of resource discovery and, most importantly, improve the decision making process. A vector-based GIS for a portion of Bonneville County, Idaho, is being used to develop and demonstrate the use of GIS techniques in the selection of oil and gas well drilling sites. The present environmental and social factors are considered. These translate into state and federal drilling restrictions, which are spatial in nature and are incorporated into the GIS database. Map overlay functions effectively assess the co-occurrence of oil and gas activity with such factors as land use and wildlife habitat. If conflicts exist, such as the presence of game or special closures or restrictions, the petroleum company can either move its well location or delay drilling, depending on the restriction. These same procedures may also be applied to assist in the decision making process when locating sites for power plants, landfills, and sub-divisions.

Introduction

To assist in the search for oil and gas, petroleum companies have always applied state of the art technology. Today this has come to mean the use of geographic information systems (Lang, 1988). Along with increased exploration, inventory, and the use of remotely sensed data, is the need to efficiently organize the rapidly growing body of information. The inherent spatial character and distribution of non-renewable resources make their associated locational data amenable to incorporation into a GIS. The use of a computerized interactive GIS to manage large and diverse data sets can enhance the probability of resource discovery and, most importantly, improve the decision making process (McLeod et al., 1983).

The analysis capabilities of the GIS model created here allows the user to ask a complex environmental question such as 'locate all areas that are within 500 feet of the normal high waterline of any and all streams, lakes, ponds, and reservoirs.' Such a GIS could be central to the development of environmental policies concerning oil and gas drilling (Gros and Williams, 1988).

Federal and state drilling restrictions vary according to the proposed drilling unit. A listing of restrictions is never complete until an environmental assessment is accomplished. Restrictions may also change without notice. The present system of cataloging particular restrictions in the selected study area is burdensome and does not lend itself to spatial queries.

The purpose of this paper is to present an example of the integration and application of GIS technology for the surface analysis necessary for oil and gas drilling site placement; it explores how computer analysis can assist both the petroleum industry and the forest service in streamlining the decision making process. By making an 'initial cut' or elimination of unfavourable sites, the GIS user can delineate quickly where drilling might be permitted in the national forest.

Study Area

The township selected for the pilot project is located in the Snake River Range, Bonneville County, Idaho. The town of Swan Valley, which lies just outside the southwest corner of the study area may be used as a reference. This township is within the Targhee National Forest, hence, the federal drilling restrictions are issued from the Palisade Ranger District office in Idaho Falls.

This study area was selected for a number of reasons. First, it possesses a number of environmental factors on which GIS buffer functions may be applied. As an area rich in wildlife, timber resources, and natural beauty, state and federal agencies are determined that environmental impacts, due to oil and gas activity, are kept to a minimum. Second, the drilling restrictions are prone to be spatial in nature; these restrictions were converted into GIS analysis functions. Finally, Bonneville County lies in the heart of the Overthrust Belt, which is described by geologists as a complex faulted and thrusted zone which runs from Texas to Canada. Certain areas of the Overthrust Belt have produced large qualities of oil and gas. Idaho has yet to produce a commercial oil and/or gas well; nevertheless, petroleum companies still search within its boundaries for hydrocarbon deposits.

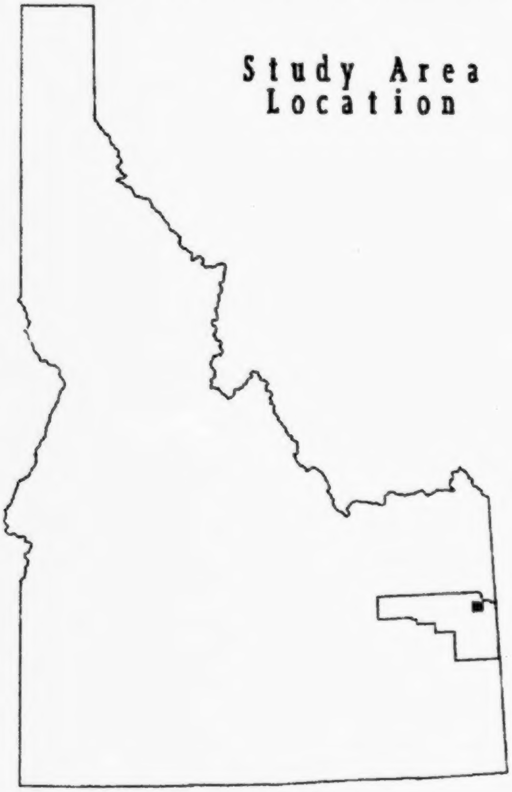

Figure 1

Methods

This study addresses the following questions:

1. how to streamline the process of selecting an oil and gas well drill site?
2. how to identify and rate alternative drill sites?
3. how to identify environmental and social factors?
4. how to create methods to quickly update drilling restrictions? and
5. how to establish a user friendly environment?

The study design is composed of five major stages:

1. identifying environmental and social factors (drilling restrictions) as stated in the environmental assessment,
2. using Environmental Systems Research Institute's ARC/INFO to develop a database that includes the drilling restrictions which are spatial in nature,
3. performing GIS spatial analysis,
4. creating maps that quickly reveal conflicts between restrictions and drilling and INFO tables that support the map data, and
5. designing a procedure for the efficient updating of state and federal drilling restrictions.

The drilling restrictions used in this study are found in the Environmental Assessments that were conducted for the drilling sites proposed by the Anschultz Corporation. Only restrictions that are spatial in nature are included in this study. Fortunately, this provides enough data from which an 'initial cut' can be made by the petroleum company's GIS staff. Restrictions that are 'non-spatial in nature' may then be used in conjunction with the GIS data to select the final drilling site.

Of extreme importance, and forming the basis for the selection of this study area, are the buffer zones of 500 feet that have been established from the centerline of any and all roads and/or highways within the lease area; and the normal high water line of any and all streams, lakes, ponds, and reservoirs. Buffer zones of 400 feet have been established from the following: any and all springs, and any

Stream Buffers
Bonneville County, Idaho
T2N R44E

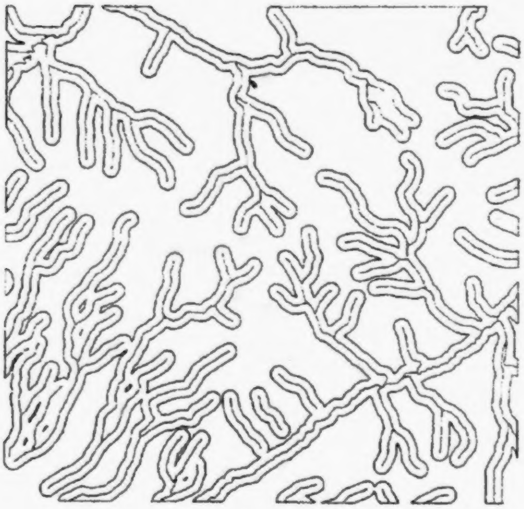

Figure 2

improvements either owned, permitted, leased or otherwise authorized by the Forest Service. Buffer zones of 200 feet have been established from any and all trails. Restrictions further stipulate that no well is to be drilled on slopes greater than 40 percent.

In stage two, individual theme layers were created from USGS 7.5 minute topographical maps. 80 foot contour lines and selected very important points (VIP) were first digitized to create the digital elevation model (DEM). The ARC/INFO command ARCTIN was used to create 3-D topology. Surface analysis was then performed to assess slopes over 40 percent. 3-D perspectives may also be generated from the TIN model for display purposes.

Individual theme layers were next created by digitizing all streams, roads, trails, and springs. These features were then buffered with their appropriate distances. To reveal the spatial relationship involved in all the buffered theme layers, the UNION command was used. The DISSOLVE command the erased the interior arcs within the overlaid polygons.

Results

The purpose of this pilot study was to determine where oil and gas activity may be conducted within a portion of the Targhee National Forest. Results generated from the GIS model are only an initial cut. Non-spatial restrictions, such as game closures, still need to be factored into the site analysis.

3–D Perspective
Bonneville County, Idaho
T2N R44E

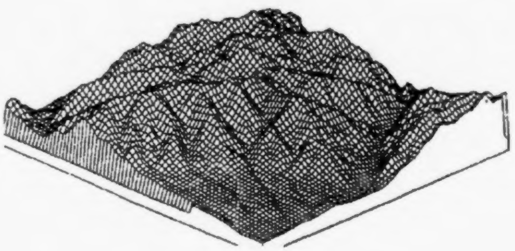

Figure 3

Drilling acreage was drastically reduced after the primary theme layers were buffered; slope analysis further reduced the acreage. Slopes that were less than 40 percent were then reclassified into parcels containing three acres or more as a minimum of three acres is necessary for the construction of the drill platform. Areas less than three acres may not accommodate the equipment necessary for drilling operations.

Environmental Buffers
Bonneville County, Idaho
T2N R44E

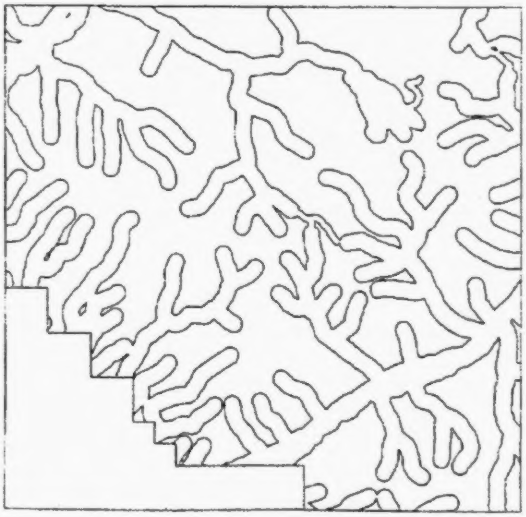

Figure 4

The availability of potential drill sites was quickly reduced as BUFFER, SLOPE, and size restriction commands were applied to the theme layers. The criteria used for the above commands translated directly from the Environmental Assessments. These restrictions, if loosened in whole or in part, could increase the acreage where drilling is allowed. When mitigation of a particular regulation was found to be necessary, the GIS model could quickly be modified and the analysis re-run.

Summary

This pilot study has examined environmental restrictions pertaining to oil and gas activity in the Targhee National Forest. A GIS was used to show the spatial relationships between certain drilling restrictions in the study area. Results suggest that a variety of factors greatly reduce the availability of possible drilling sites. Hydrological features and wildlife habitats are important determining factors when addressing the selection of the drilling site.

GISs are rapidly assuming roles as nerve centers in decision support facilities for the management of environmental resources; they are particularly convenient for overlaying multiple information elements and mapping the occurrence of critical combinations of features (Myers, 1983). A GIS stores, manipulate, and displays geographically referenced information. However, a GIS is more than just a repository for massive volumes of data; it is a system for organizing and presenting information needed by researchers, managers, and policy makers (McLeod, 1983).

Acknowledgement

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GIS and Sustainable Development in Forest Management

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Abstract

While soaring to popular importance with the public, the media and politicians, the concept of sustainable development seems very familiar to foresters. The foresters' perspective began with sustained yield objectives and has been significantly enhanced with the adoption of integrated resource planning and management. But sustainable development adds new challenges to 'good forest management', including greater consideration to alternate values and to uncertainty and increased public demand for participation in decision making.

GIS has emerged as a credible resource management tool and provides many opportunities for improved performance in applying sustainable development principles to forest management. This paper explores the requirements of sustainable development and examines how GIS can be applied to achieve sustainable development in resource management.

Introduction

What is sustainable development?

"Naturally enough, a concept not clearly and consistently defined, with strong emotional appeal, whose economic rationale is more difficult to grasp than might appear at first sight, has been utilized for furthering objectives that are not necessarily in harmony with it."

Surprisingly, in the above quote from S.V. Ciriacy Wantrup's classic natural resource economic text, **Resource Conservation**, he is referring to conservation, not sustainable development. The statement is applicable to both concepts. Both have considerable emotional and ethical appeal, both have been identified as 'Wise Use', whatever that means to each of us. One thing we can be sure of: sustainable development will be buzzwords for the 1990's and beyond.

There seems to be a tradition that when we talk about sustainable development, we begin by offering our own definition of the concept. This tradition helps to explain why support for sustainable development is something on which both impassioned environmentalists and hard-nosed business leaders can agree, and also why a lot of people are not sure what the term means. The Canadian Institute of Forestry (CIF, 1990) supports the philosophy of sustainable development as defined in the 1987 World Commission on Environment and Development report, **Our Common Future** often called the Brundtland Report: development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Further, this is 'a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs'. This is the definition we support in this paper.

Sustainable development does not mean no development, it means improving methods for resource development in an environment of increasing demand for resources. **Our Common Future** suggests that the global GNP must be increased to achieve an adequate and equitable standard of living for all.

Economic trends have always had an impact on environmental trends although the impact was sometimes seen only in retrospect and was frequently discounted. We are now seeing environmental trends beginning to show very real impacts on economic trends.

How does sustainable development differ from sustained yield management?

To foresters, sustainable development sounds very familiar; we proudly claim to be among the originals through the practice of sustained yield. If so, why is there such a strong negative perception of the forest industry? Recent public opinion surveys have highlighted a growing dissatisfaction with the way we are perceived to be doing business. A disturbing percentage of the public believe that the forest industry is causing irreversible harm to Canada's forests, and that there is too little government regulation over the forest industry.

Forestry should be a good candidate to lead the way with sustainable development. Well-managed forestry operations could be the equivalent of the Brazilian rubber tree tappers, whose defence of the rain forest against slash-and-burn cattle ranchers has made them international heroes. Sustainable economic activity forestalls non-sustainable, destructive practices by making the forest more valuable intact than destroyed. Because forests are a renewable natural resource, they have the potential to be used perpetually for the full spectrum of economic, environmental and social objectives.

While sustained yield management sounds a lot like sustainable development, there are basic ways of thought that must be changed for forestry achieve sustainable development. The attitude that wilderness areas, parks, buffers, wildlife habitat, etc., are direct withdrawals from productive timber land must be replaced. Forest product extraction is one legitimate use of a forest, not the only one, and not the default one. The overwhelmingly negative public perception of forestry practices underscores a gap between expectations of sustainable forests and the reality of sustained yield management.

Forests are a mainstay of balanced ecosystems and provide watershed protection and regulation, wildlife habitat, protection of air and water quality, and provide a wide pool of genetic resources as well as a range of recreational opportunities.

Forests are a notably valuable resource to the world (Forestry Canada, 1990). Forests cover one third of the world's land area; our forests in Canada account for 10 per cent of the world's forested land. In 1987, Canada accounted for 15 per cent of the world's total coniferous roundwood harvest and 16 per cent of softwood lumber, 15 per cent of the world's wood pulp, and was the leader in the manufacture of newsprint, producing 32%. In 1988, the forest sector contributed 3.6 per cent to Canada's gross domestic project and directly employed more than 285 000 people. Forest products represent 18 percent of Canada's total exports and are the largest single earner of foreign exchange.

Sustained yield forest management concentrates on the economic values of forest products. Sustainable development encompasses the many and varied values embodied within the forest ecosystem.

There are a multiplicity of features that can be sustained, and an infinite number of possible levels at which each of those features can be sustained (Baskerville, 1989). Sustaining any one feature, at any given level, does not mean all or any of the other features are also being sustained. Therein lies the basis of the public versus professional deviation with respect to sustainability in the forests of Canada: what do we need; sustainability of volume, sustainability of quality, sustainability of environmental quality, or sustainability of habitat? Sustainability will remain a dominant issue in forestry over the next decade.

How do we move from sustained yield to sustainable development?

Our Common Future recommends that, to achieve sustainable development, we must integrate economic and ecological considerations in decision making. This integration requires:

- a political system that secures effective citizen participation in decision making;
- an economic system that is able to generate surpluses and technical knowledge on a self-reliant and sustained basis;
- a social system that provides for solutions for the tensions arising from disharmonious development;
- a production system that respects the obligation to preserve the ecological base for development;

- a technological system that can continuously search for new solutions;
- an international system that is flexible and has the capacity for self-correction; and
- an administrative system that is flexible and has the capacity for self-correction.

Foresters are not directly responsible for the achievement of all these requirements, but there are many opportunities available to move beyond the sustained yield process to sustainable development. The challenge is to conduct, profitably, more intensive forest management, most probably on a decreased land base. We need the ability to anticipate problems in order to take action in time.

Maini (1989) suggests three considerations are necessary to achieve sustainable development of the forest resource:

- understanding the capacity of the forest to sustain a range of uses while maintaining diversity;
- managing activities within the forest's environmental capacity; and
- using or manipulating the forest environment without prejudicing its ecological integrity and use by future generations.

Integrated Resource Management

The general wide level of acceptance of an integrated resource management approach was the first major step. Most, if not all, government agencies and companies now recognize an integrated approach as a routine process as opposed to an exotic technique.

Refinements are still required. The theory of integrated resource management goes beyond bringing together a forester, a wildlife biologist and a wilderness recreationalist to agree on a plan of action: each should see the same range of opportunities and risks when they look at the same forest or forest stand.

The integrated resource management approach must include a public involvement component to insure direct consultation with constituencies formed by common issues. The public cannot participate in decision making without access to the information.

The Adaptive Approach

The adaptive environmental assessment and management approach offers guidelines and methods to assist with resolving environmental conflicts and problems. It is applicable to assessment and management projects.

Adaptive management consists of a methodically designed and scheduled series of workshops and research. The process is an ongoing and evolving approach to projects, rather than a one-shot design, and it is of particular value in situations which result in unforeseen problems.

Adaptive management is based on the assumption that because ecosystems are adaptive, to a degree, to changes in the environment, environmental management must also be adaptive (IIASA, 1979). It emphasizes the need for the inclusion of environmental factors from the beginning of the policy design process, the involvement of all stakeholders and the ongoing gathering of relevant information, rather than attempts to gather all the necessary data first. Attempts at comprehensive surveys at the beginning of a project frequently accomplish only expensive, lengthy delays and reams of uninterpreted, unnecessary data yielding no insight to the changes about to occur.

The use of computer models is encouraged as part of the adaptive management to simulate ecosystem, social and economic changes resulting from an action, or choices. The Gulf Island Recreational Land Simulation (GIRLS) study may be familiar to some local foresters (Holling, 1980). It was initiated in 1968 to address varied and increasing demands on resources and ecosystems. Work was stopped in 1970, and, while all the problems were not solved, several key achievements were accomplished, and several key stumbling blocks uncovered. Several of the models developed have continued to accurately predict changes. The adaptive management approach itself is adaptive, and learns from failures and much as from successes.

The availability of relevant data and consensus across a diverse group of experts enables the adaptive management approach to provide alternatives which are not only astute, but which can be convincing messages to political decision makers.

Economic Analysis

The potential for non-sustainable development of forests has two primary sources: the so-called nonexclusivity or commons issue, and the wide range of commercial and industrial interests whose decisions affect what happens to the environment but who rarely benefit directly from actions that protect it, or suffer from actions that harm it (Crocker, 1988).

Economic analysis, such as a benefit-cost study, taking into consideration all benefits and costs, can provide a more balanced frame of reference for decision makers by providing some indication of the effect of considered changes. Benefit-cost analyses can yield qualitative and quantitative information about economic and environmental tradeoffs and are tools to support decision making. The weakness of mainstream economic theory as a decision support tool lies in an inability to provide guidance for research or policies to encourage innovation, or to offer a satisfactory perspective across the necessary range of issues and disciplines and effects over time of effects (Mowery, 1990).

Regulations and Incentives

Government regulations and pricing structures will be employed to reflect accurate assessments of real benefits and costs, but it is likely these will not have as great an effect as the growing pressures from consumers. Better public understanding of environmental impacts is already being exhibited in changing market demands, and technology is rapidly advancing to satisfy the new demands. The entire forestry industry is well aware of the pressures to behave as responsible corporate citizens.

The Tool to Bring Them All Together: GIS

Information technology provides a mechanism for managing complexity. Given the size of the land areas, the multitude of interests, and the diversity of resources, the quantity of information exceeds the capacity of a manual system to effectively produce relevant information for decision making. This is particulary true within what is increasingly becoming an iterative process of developing, reviewing, and refining alternatives.

Resource utilization research can help to better identify potentials and limitations and to provide the same or greater benefits from the same or a decreased land base. Integrated resource management, including a strong public involvement component, can improve the development of goals and objectives encompassing all the values of a forest. Adaptive management can provide a framework for the trial and error process of determining what the changes will be and how best to react to them. Economic analysis, regulations and incentives will help to guide us in the right direction.

However, none of these tools are viable without accurate, current information to achieve reliable results.

Geographic information systems have only recently progressed to a stage where they can be used effectively in this complex situation. How can GIS be effectively used to facilitate new land management concepts embraced by sustainable development?

Records Management

A large part of society's need for information is related to the land. Day to day policy making, management, planning and government services are hindered by an inability to associate much of the required land-related information with its physical location. Current GIS are alleviating some of these problems. However, records management must be more than maintaining resource inventories and land use status. Decision making also requires information about the events and impacts of management intervention. More needs to be done to capture events and experiences in addition to measurements and observations of natural resources. This implies that forestry practitioners must record more of the day-to-day activities of resource management and that the systems must better facilitate such capture. New technology for monitoring, connected to information systems by telemetry, and more sophisticated earth observation systems will also provide more current data.

Predictive Modelling

Geographic data bases interfaced to predictive models can provide resource professionals and decision makers with the capability to undertake more 'What if' analyses and comparison of alternatives. Long-term wood supply models connected to GIS are being developed in Canada and the US. Many current planning models are deficient in accommodating integrated resource management concerns, and lack the facility to record experience and to be modified accordingly. The process should include feedback mechanisms that can record the effects of management actions based on simulations and other data analysis and lead to refinement of the models. Again, this may mean that more of the day-to-day activities must be recorded to provide the data to calibrate the models and that resource professionals will spend more time analyzing and interpreting data.

Support for Public Involvement

Having accurate data and being able to communicate it effectively will help to eliminate the value-laden arguments about how much should, and can, be done. GIS can be used to resolve conflicts by presenting the facts to stakeholders in an open forum in which alternatives can be tested. This approach is already being effectively used to resolve many urban land use conflicts. Conflicts result in part from data that is inadequate for clear, undisputed decision making which is both environmentally and economically sound. GIS will be used to deal with resource conflicts by managers who have the courage and willingness to state their goals, to make their plans of action public, and to rationalize how these actions will serve to achieve the goals, to monitor the results or their actions, and to seek explanation of the variance between forecasts and actual outcomes. When used effectively, an information system is not merely a static collection of facts, but a dynamic distribution network for ideas (Baskerville and Moore 1987).

Environmentalists are accused of overstating the issues while developers are accused of basing decisions on short-term economic gains. The general public is unable to obtain a clear picture of the relative degrees of importance of the issues, and it is difficult for politicians to support expensive decisions to support long-term sustainable development (Anderson 1989). For example, over 50% of the sampled population in Richmond didn't know the difference between primary, secondary or tertiary sewage treatment and their relative costs, but they were sufficiently concerned to vote on the issue (Maini and Carlisle 1974). GIS technology can facilitate information integration, cost-effective distribution and promote a multipartite process.

Groupware and GIS

System vendors are developing a new product called groupware that will make it possible for multi-disciplinary teams to work more effectively on resource planning problems. Data and analytical processes can be shared by several users, each working at their own workstation but able to see the effects of another's analysis. It is analogous to an electronic boardroom that does not require the participants to be in the same location. This technology has yet to be added to any commercial GIS, but, given the pace of development, it is likely not far away. Multi-disciplinary planning has been frustrated by communication problems, caused by differences in jargon, and long delays before the information to support a concern could be provided. Groups of professionals working from consistent data bases, with known constant analysis models, can focus on selecting the best alternative to meet policy objectives, rather than arguing whose information or interpretation is correct.

Conclusion

The challenge of incorporating sustainable development concepts into already complex resource management will be significant, but it is a challenge which must be met. As Gordon Baskerville concluded from his audit of Ontario's Crown Land timber management in 1986: "If there is a dominant feature ... it is the prevalence of all-purpose solutions to non-specific problems." Properly developed and applied, GIS technology can do much to facilitate the development of specific solutions to the complex problems of achieving sustainable development.

It is very easy to become absorbed in the engrossing components of hardware, graphic devices, formats, accuracy assessments, and implementation standards. It is also very easy to be protective of mandates, programs and issues. The challenge we face entails the need to look beyond these day to day preoccupations, to envision new models and opportunities, and to work towards sustainable development using accurate, shared information.

Geographic information systems can provide us with the tools to go beyond the current situation and to make sustainable development both practical and effective.

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The Application of a GIS System for Optimizing Multiple Land Use

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Abstract

At the Universitaet fuer Bodenkultur (Univesity of Agriculture) in Vienna, a GIS application is being developed, using ARC/INFO- software, which uses different layers of environmental information in order to optimize land use according to a user-defined system of preferences. By applying a ranking system of preferences, each part of the evaluated areas can be assigned all those types of land use which are without negative impacts on higher ranked types. Possible conflicts can also be visualized by extracting mutually excluded land uses. This paper describes the results of the test run of the system, evaluating parts of the Viennese Forest, which represent problems typical of areas neighbouring urban regions.

Introduction: The Problems of Forestry in an Urban Region

To the south and the west of the City of Vienna is a large belt of forest land, called the Vienna Woods. These forests have always been of vital interest to the people living in Vienna. Up to the last century they served as a resource for fuel and construction wood, which resulted in the almost complete deforestation of that area. But in the middle of the 19th century, the danger became so evident that logging was finally reduced to a sustainable level.

Today, these forests must fulfill a multitude of functions and are subject to the growing demands of society in an urban region. First, they have to serve as a recreation area for the city, where about 50% of the citizens surveyed (Glueck, 1984) named walking or hiking in the forests as their favorite recreational activity. The forests around the city also have to ensure ecological balance, especially since they represent areas of minor human influence on nature. The welfare function of these forests is also important, since they serve as a filter against air pollution. The expansion of the city has resulted in development activities and many new settlements were established on former forest land, sometimes without the proper permmission. The traffic in and around the city also causes negative impacts on the forest, either by the construction of new highways and roads or by air pollution. There is a lot of hunting activitiy in these forests, which, because of the district-oriented hunting system in Austria, results in high deer stands and the danger of deer damage.

Finally, one must not forget that a large part of these forests are privately owned and that these owners have a legitimate right to manage their forest land according to the principle of sustained yield.

Forest regional planning is a rather young discipline in Austria but, as the problems of concurrent interests in forest land use increase, so does the importance of planning activities in order to avoid possible conflicts. Geographic information systems may provide an important tool for forest regional planning, as the handling and evaluation of spatial data is one of the main tasks in these planning activities. To explore the possibilities of GIS use in this field and to present future foresters with this technology, a GIS system approach to optimize different types of forest land use has been tested during a course in Forest Regional Planning at the Universitaet fuer Bodenkultur in Vienna.

The Study Area

The Lainzer Tiergarten (Lainz Deer Park) is an area of about 2500ha in the Vienna Woods, where all of the above problems are present. In the second half of the 18th century, a wall of about 2m height was built around this area by order of Empress Maria Theresia. The main purpose was to keep the deer inside the Imperial hunting grounds, so that deer damage to the farmlands around would be prevented. Since then, this area has been a hunting reserve, and even today about 80 % of the area is closed to the public from November to March. The high game stand in this area has resulted in heavy deer damage and any form of forest regeneration is possible only within fenced areas.

On the other hand, this is one of the most important recreation areas in the Vienna Woods, as it is situated within the borders of the city and is easily accesible by public transport.

There are also some areas of special ecological value, some of which already have been declared nature reserve zones, but conservationists would like to have theses zones enlarged and given a higher class of protection.

Some of the sites in this area are capable of producing high quality oak for veneers, and so there is also a large interest in regular forest management in these areas.

Concepts of Land Use Optimization

The four most important forest land use activities in the study area were selected, in alphabetical order:

- Hunting;
- Nature Conservation;
- Recreation; and
- Wood Production.

Each part of the study area has a potential for each of these land use activities, but some activities have a negative influence on others, and it is not always possible to practice all of them in the same area at the same time. It is therefore necessary to apply a ranking system, so that in the case of negative interference only the higher-ranked land use activity will be assigned to a certain area.

Preference System Definition

It is obvious that a ranking between these activities depends on the individual preferences of the evaluating person or authority, as a forester will apply differentpreferences than a conservationist or a tourist manager. One of the goals of the project was to get the students to visualize the differences between the preferences of regional planning and those of the forest sector.

Therefore, two systems of preferences were established, a regional and a sectoral one.

The Regional Preference System

For the regional planner, the study area represents a large potential for recreation and environmental compensation for the urban region of Vienna. Therefore, recreation and nature conservation are considered most important. In this system, wood production is ranked third, as it is of higher economic importance than hunting.

The regional preference system is:

1. Recreation;
2. Nature Conservation;
3. Wood Production; and
4. Hunting.

The Sectoral Preference System

This system was established to reflect the interests of the forest sector. Wood production is considered most important and is ranked first. Hunting is ranked second, as the selling of hunting licences is also a potential source of income for the owners of forest land. Nature conservation is ranked third, as it is an important value for foresters, even though it does not render any profit to the land owner. Recreation is ranked fourth, as it causes negative impacts on forest management, without giving the land owner the possibility of finacial benefit. On this last point, according to Austrian Forest Law, access to private forest land for recreational purposes cannot be restricted by the land owner. This right of access does not apply to activities such as off-road driving or mountain biking.

The sectoral preference system is:

1. Wood Production;
2. Hunting;
3. Nature Conservation; and
4. Recreation.

Evaluation of Land Use Potentials

For each of the selected land use activities, there is a large variety of potential realisations, according to the potential offered by site conditions. For the land use type *Wood Production*, for example, the variety ranges from even-aged stands of Norway spruce, where large area clear cuttings are applied, to uneven-aged stands of deciduous and non-deciduous trees with the application of selective cuttings.

The first step was to evaluate the potential for each of the selected land use ctivities, using different sources of spatial information. The comparison of potential and present situation then allows the planner to establish a list of measures to achieve the potential optimum on each part of the study area. Within this step, the evaluation for each land use type was done without any regardments to other land use types. Four groups of students were assigned the evaluation of the four different land use types. Each group was told to define the solutions for its land use type as extremely as possible, so that in a later step the possible conflicts between the different land use types would be more evident.

Sources of Information

Digitized Data

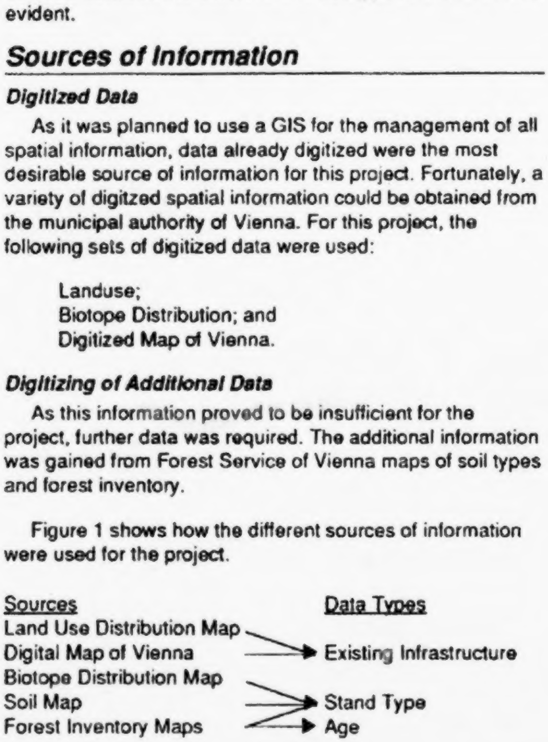
As it was planned to use a GIS for the management of all spatial information, data already digitized were the most desirable source of information for this project. Fortunately, a variety of digitzed spatial information could be obtained from the municipal authority of Vienna. For this project, the following sets of digitized data were used:

Landuse;
Biotope Distribution; and
Digitized Map of Vienna.

Digitizing of Additional Data

As this information proved to be insufficient for the project, further data was required. The additional information was gained from Forest Service of Vienna maps of soil types and forest inventory.

Figure 1 shows how the different sources of information were used for the project.



	Data Types		
Preferred Land Use Activities	Stand Type	Age	Existing Infrastructure
Hunting	C	C	P, C
Nature Conservation	P, C	--	--
Recreation	P, C	C	C
Wood Production	P, C	C	--

P: used to evaluate future potential
C: used to evaluate current situation

Figure 1. Sources and Types of Data Employed

Evaluation Process

Different potential areas for each land use activity varied. For example, about 12 potentials existed for *Wood Production* and only 2 for *Hunting*. In order to compare the potential of one land use activity with another, a standard had to be defined which would allow such comparisons. Therefore, the number of potential classes for each land use type was reduced to three, where class 3 would be the most desirable for a certain land use type and class 1 the least desirable. A full listing and explanation of the potential classes for land use types would be excessive, so the following is only a rough summary of the potentials assigned to each class.

Evaluation for Land Use Wood Production

The soil map was used to get information on the potential for this land use activity within the study area. For information on the current situation, the forest inventory of the municipal forest service was used for the areas within the Lainz Deer Park, as these areas are municipal property. For the outside areas, the biotope distribution map was used.

Priority potential classes for use type *Wood Production*

CLASS	POTENTIAL
W3	Oak veneer Other deciduous trees Norway spruce, Austrian pine
W2	Reforestation of grass land (energy wood plantations, Christmas tree production)
W1	Protection forests, wetlands

Evaluation for Land Use Hunting

To define potentials for this activity, existing installations were also included into the evaluation process. The group responsible for this land use activity defined two types of potential, where the wall around the Lainz Deer Park is the main criterium for the spatial distribution of these types. Inside the deer park, a very intensive hunting management would be applied, including a raise-in deer stand, with accompanying measures such as intensive feeding. Outside the wall, an extensive system would be applied, including a reduction of deer stands to a sustainable level such that deer damage would be eliminated.

Priority potential classes for use *Hunting*

CLASS	POTENTIAL
H3	Intensive hunting (inside deer park)
H1	Extensive hunting (outside deer park)

Evaluation for Land Use Nature Conservation

The soil map was also used for this activity, whereas the present situation was taken from the biotope distribution map.

Priority potential classes for use type *Nature Conservation*

CLASS	POTENTIAL
N3	Dry meadows Wetlands Riparian buffers
N2	*Quercus cerris* *Quercus pubescens* *Pinus silverstris*
N1	*Quercus sp. / Carpinus betulus* *Quercus sp. / Fagus sylvatica* *Fagus sylvatica / Abies alba*

Evaluation for Land Use Recreation

The evaluation for this land use activity was based on site conditions and the presence of an existing infrastructure. The main part of the classification was the definition of zones for intensive recreation activities on one hand and those for extensive activities on the other hand.

Priority classes of potentials for *Recreation*

CLASS	POTENTIAL
R3	Free areas for intensive activities up to 20% of the test area (lunch areas, resting places, etc...)
R2	Maintenance of areas around existing infrastrucuture (e.g., restaurants)
R1	Medium-aged mixed stands

Information overlays

For all parts of the study area, a full geometric and thematic overlay was performed for all of the described information input layers. The resulting layer was then used to assign the potential classes as described above. Each polygon of this new layer contains the information of all basic input layers as well as the information on the assigned land use potentials.

Definition of Interference Matrices

During the next step of the project, the interferences between the different potential classes for all use types were evaluated. Six matrices were defined, each of which contains the comparison between two land use types. These matrices are listed below; a '0' means negative interference between two classes, a '1' means that no interference occurs.

RECREATION / NATURE CONSERVATION

	R3	R2	R1
N3	0	0	1
N2	0	1	1
N1	1	1	1

RECREATION/ HUNTING

	R3	R2	R1
H3	0	0	0
H1	1	0	1

NATURE CONSERVATION / HUNTING

	N3	N2	N1
H3	0	0	0
H1	1	1	1

RECREATION / WOOD PRODUCTION

	R3	R2	R1
W3	0	0	1
W2	0	0	0
W1	0	0	1

NATURE CONSERVATION / WOOD PRODUCTION

	W3	W2	W1
N3	0	0	0
N2	0	0	0
N1	0	0	0

WOOD PRODUCTION / HUNTING

	W3	W2	W1
H3	0	0	0
H2	1	0	1

Optimizaiton of Land Use According to Preference Systems

The main step was to define land use combinations, according to the defined preference systems, with regard to the interference matrices. First, a ranking between the potential classes of all land use types was established for each of the two preference systems.

Ranking for regional system preferences

Rank:	1	2	3	4	5	6	7	8	9	10	11
Pot.:	R3	R2	N3	R1	N2	W3	N1	W2	H3	W1	H1

Ranking for sectoral (forestry) system of preferences:

Rank:	1	2	3	4	5	6	7	8	9	10	11
Pot.:	W3	W2	H3	W1	N3	H1	N2	R3	N1	R2	R1

With this ranking performed, it was possible to select the highest ranked land use potential for a certain area as the LEADING LANDUSE TYPE (LLUT). Any other type of land use on this area can then only be undertaken if it does not interfere with the LLUT.

According to the criteria defined,a certain area was assigned the following land use potentials:

WOOD PRODUCTION	3	W3
HUNTING	3	H3
NATURE CONSERVATION	2	N2
RECREATION	1	R1

In the *Regional* preference system, these potentials are ranked R1 > N2 > W3 > H3

So *Recreation*, with potential class R1 is the LLUT in this area. Ranked next is N2. According to the interference matrix, there is no interference between R1 and N2, so *Nature Conservation* with potential class N2 is also assigned to this area. In the interference matrix, the next potential W3 interferes with N1, so *Wood Production* will not be assigned to this area. The same applies to *Hunting*, as H3 interferes with R1.

In the *Sectoral* system of preferences the ranking is: W3 > H3 > N2 > R1. In this system *Wood Production* is the LLUT for this area, and *Hunting* is not assigned to this area, as there is interference between H3 and W3. There is also interference between N2 and W3, so *Nature Conservation* will not be assigned to this area. R1 does not interefere with N2 or W3, the interference between H3 and R1 is irrelevant, as H3 is not assigned to this area, thus *Recreation* with the potential class of R1 is also assigned to this area.

Automatization of Land Use Assignment

Basically, the method which was applied for land use optimization in this project is a system of vector and matrix operations, which can easily be formed into a system of logical algorithms. The ARC/INFO AML-Arc Macro Language allows the programming of such operations and so an AML program was written to perform the described land use assignment. Figure 2 shows the flowchart of this applcation. The use of a programming language like FORTRAN or C for this purpose would permit faster and more efficient computation, but from the author's point of view, minimum run time is not very essential in this project and the features of AML are sufficient for the desired purpose. By using an AML program, it is also very easy to start this program from other AML applications, such as a customized menu system.

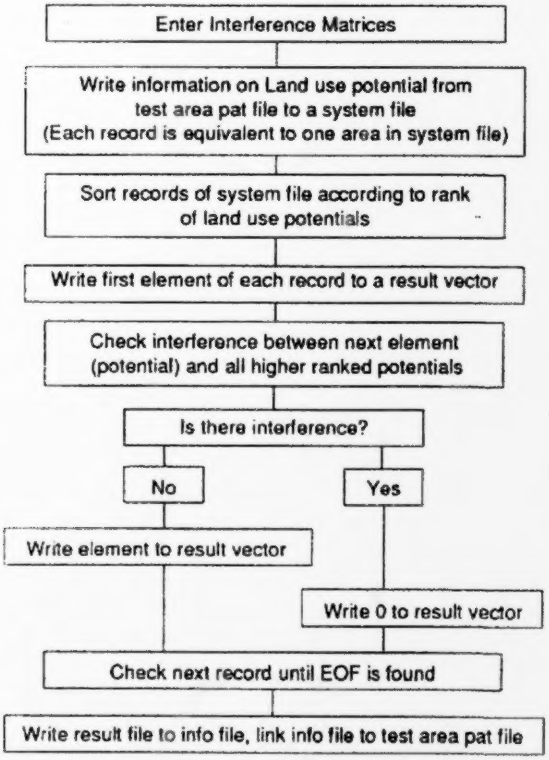

Enter Interference Matrices
Write information on Land use potential from test area pat file to a system file (Each record is equivalent to one area in system file)
Sort records of system file according to rank of land use potentials
Write first element of each record to a result vector
Check interference between next element (potential) and all higher ranked potentials
Is there interference?
No
Yes
Write element to result vector
Write 0 to result vector
Check next record until EOF is found
Write result file to info file, link info file to test area pat file

Figure 2. Flowchart for USEVAL.AML

Land Use Assignment Maps

With the optimized land use assignments performed, the GIS can produce maps showing the distribution of the assigned land uses for the whole study area, as shown in Figures 3 and 4, based on the regional and sectoral preference systems, respectively.

Conflict Maps

The exclusion of a certain land use from an area means that conflicts will arise with all those people who have an interest in the now-excluded land use. With the information stored in the GIS, it is possible to produce maps that show which land use types are excluded from what areas. These maps are the inverses of the land use assignment maps. Figures 5 and 6 are conflict maps based on the regional and sectoral preference systems, respectively.

Necessary Action Maps

The result of all the information overlays contains not only information on the land use potentials but also information on the current situation. By comparing the potential with the current situation, it is possible to define a list of actions which have to be taken to turn the current situation into the potential optimum. These lists are established for all land use types. For a given area, those actions necessary to reach the potential optimum for the LLUT (leading land use type) will be taken.

After the assigment of necessary actions has been performed by a system of 'IF-THEN' operations, this information can be mapped. Figures 7 and 8 are necessary action maps based on the regional and sectoral preference systems, respectively.

Here is a short description for each of the listed actions.

Actions for LLUT *Wood Production*:
W1: Current situation is the potential optimum; continue current management practices
W2-W7: Current situation is not the potential optimum; change management practices to reach desired optimum

Actions for LLUT *Hunting*
H1: Immediate cutting of stands older than 70 years (shorten falling cycle to 70 years)
H2: Convert non-deciduous monocultures to mixed stands

Actions for LLUT *Nature Conservation*
N1: Current situation is the potential optimum; preserve it
N2: Current situation is not the potential optimum; change vegetation types and density

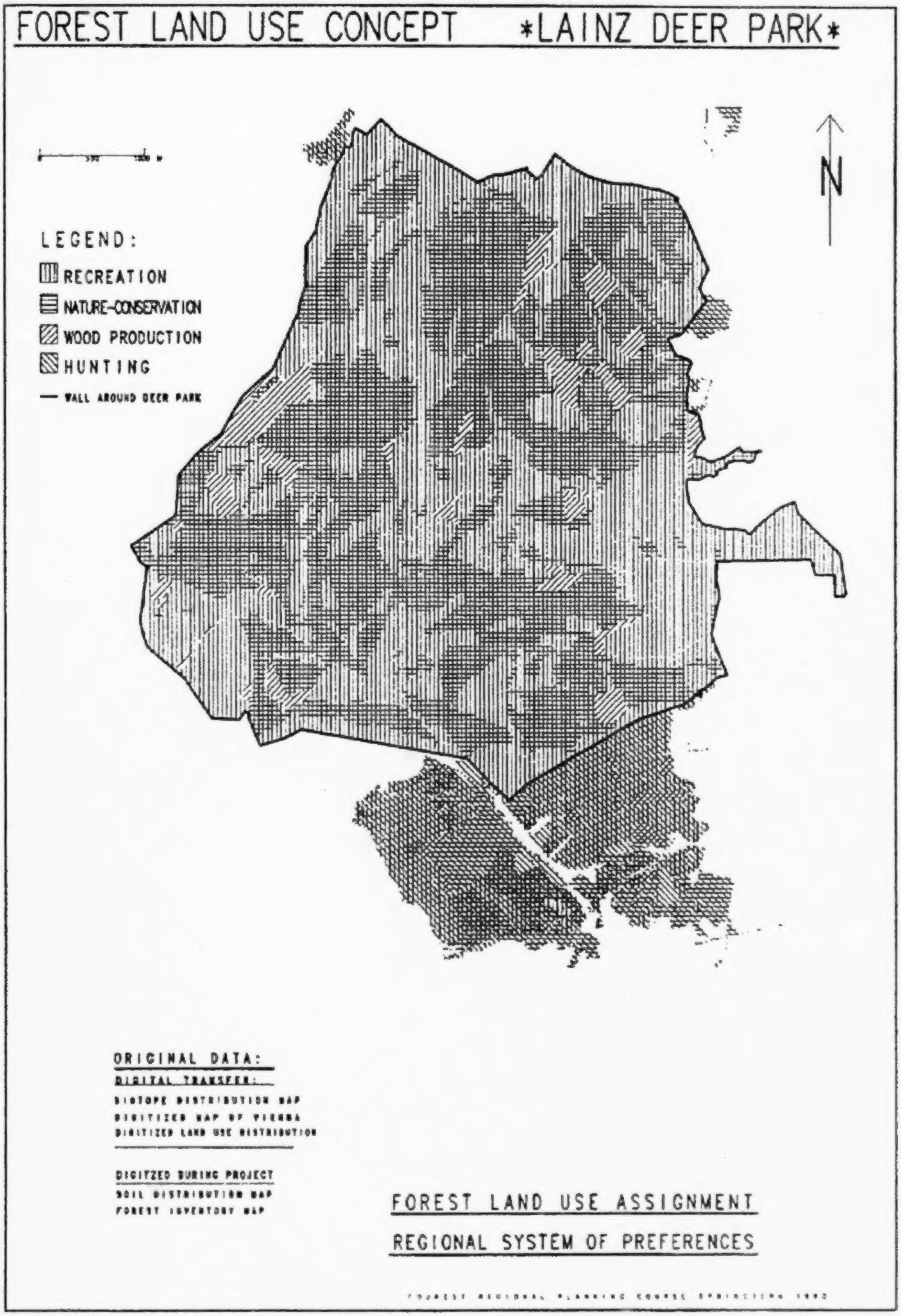

FOREST LAND USE CONCEPT *LAINZ DEER PARK*
0
500
1000 m
N
LEGEND:
RECREATION
NATURE-CONSERVATION
WOOD PRODUCTION
HUNTING
WALL AROUND DEER PARK
ORIGINAL DATA:
DIGITAL TRANSFER:
BIOTOPE DISTRIBUTION MAP
DIGITIZED MAP OF VIENNA
DIGITIZED LAND USE DISTRIBUTION
DIGITZED DURING PROJECT
SOIL DISTRIBUTION MAP
FOREST INVENTORY MAP
FOREST LAND USE ASSIGNMENT
REGIONAL SYSTEM OF PREFERENCES

Figure 3. Forest Land Use Assignment, Regional System of Preferences

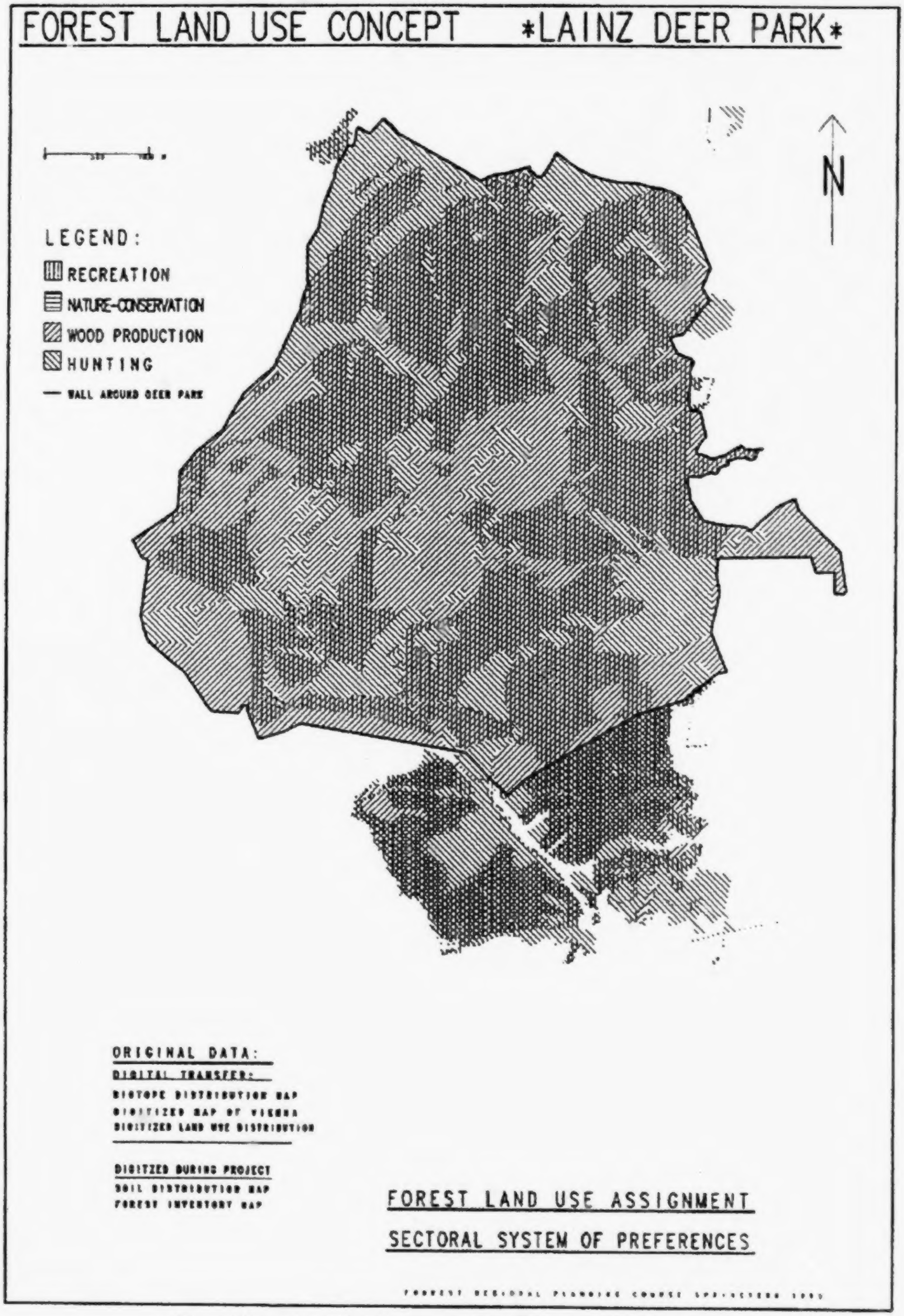

FOREST LAND USE CONCEPT *LAINZ DEER PARK*
N
LEGEND:
▥ RECREATION
▤ NATURE-CONSERVATION
▨ WOOD PRODUCTION
▧ HUNTING
— WALL AROUND DEER PARK
ORIGINAL DATA:
DIGITAL TRANSFER:
BIOTOPE DISTRIBUTION MAP
DIGITIZED MAP OF VIENNA
DIGITIZED LAND USE DISTRIBUTION
DIGITZED DURING PROJECT
SOIL DISTRIBUTION MAP
FOREST INVENTORY MAP
FOREST LAND USE ASSIGNMENT
SECTORAL SYSTEM OF PREFERENCES

Figure 4.Forest Land Use Assignment, Sectoral System of Preferences

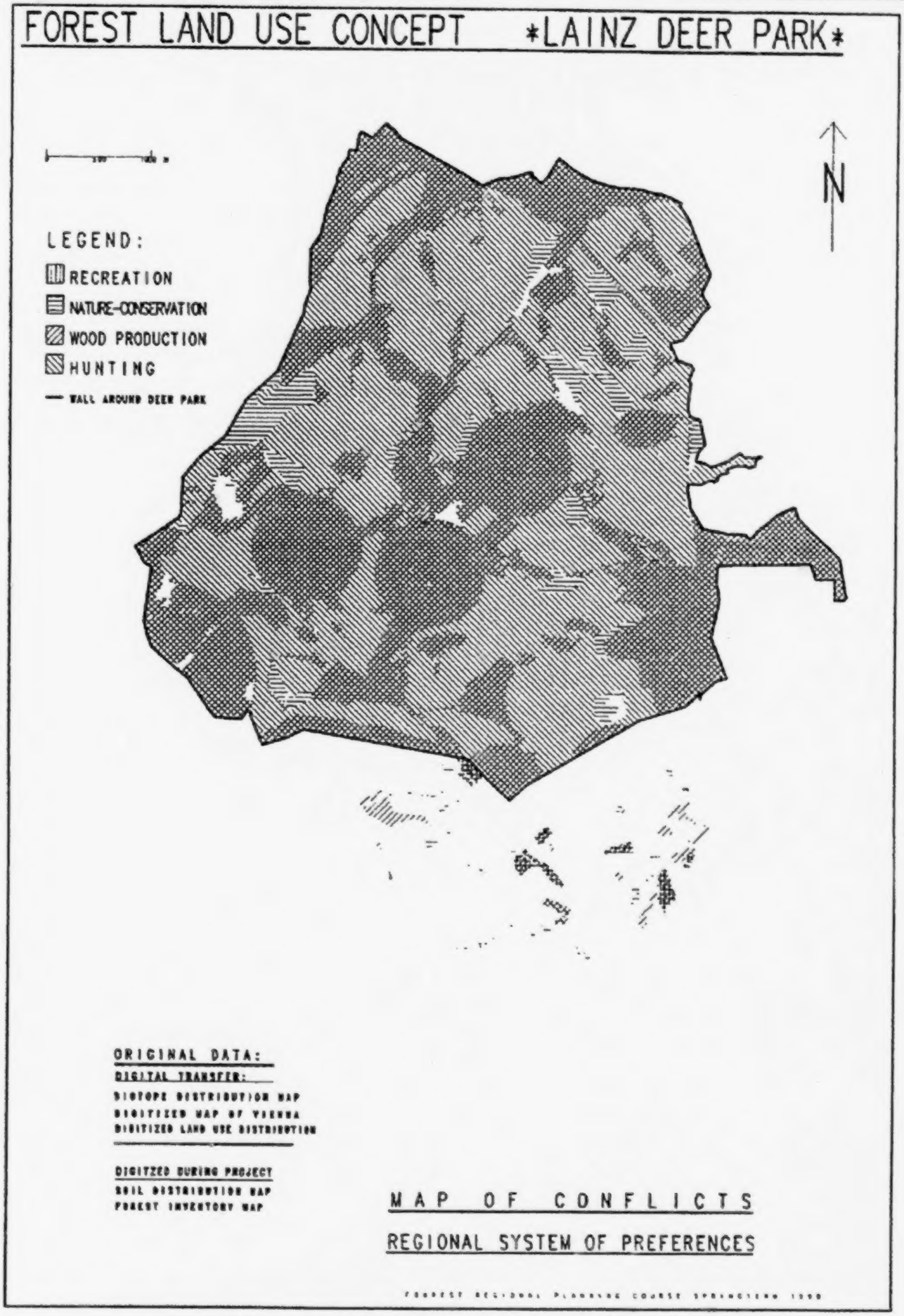

FOREST LAND USE CONCEPT *LAINZ DEER PARK*
N
LEGEND:
RECREATION
NATURE-CONSERVATION
WOOD PRODUCTION
HUNTING
WALL AROUND DEER PARK
ORIGINAL DATA:
DIGITAL TRANSFER:
BIOTOPE DISTRIBUTION MAP
DIGITIZED MAP OF VIENNA
DIGITIZED LAND USE DISTRIBUTION
DIGITZED DURING PROJECT
SOIL DISTRIBUTION MAP
FOREST INVENTORY MAP
MAP OF CONFLICTS
REGIONAL SYSTEM OF PREFERENCES
FOREST REGIONAL PLANNING COURSE SPRINGTERM 1990

Figure 5. Map of Conflicts, Regional System of Preferences

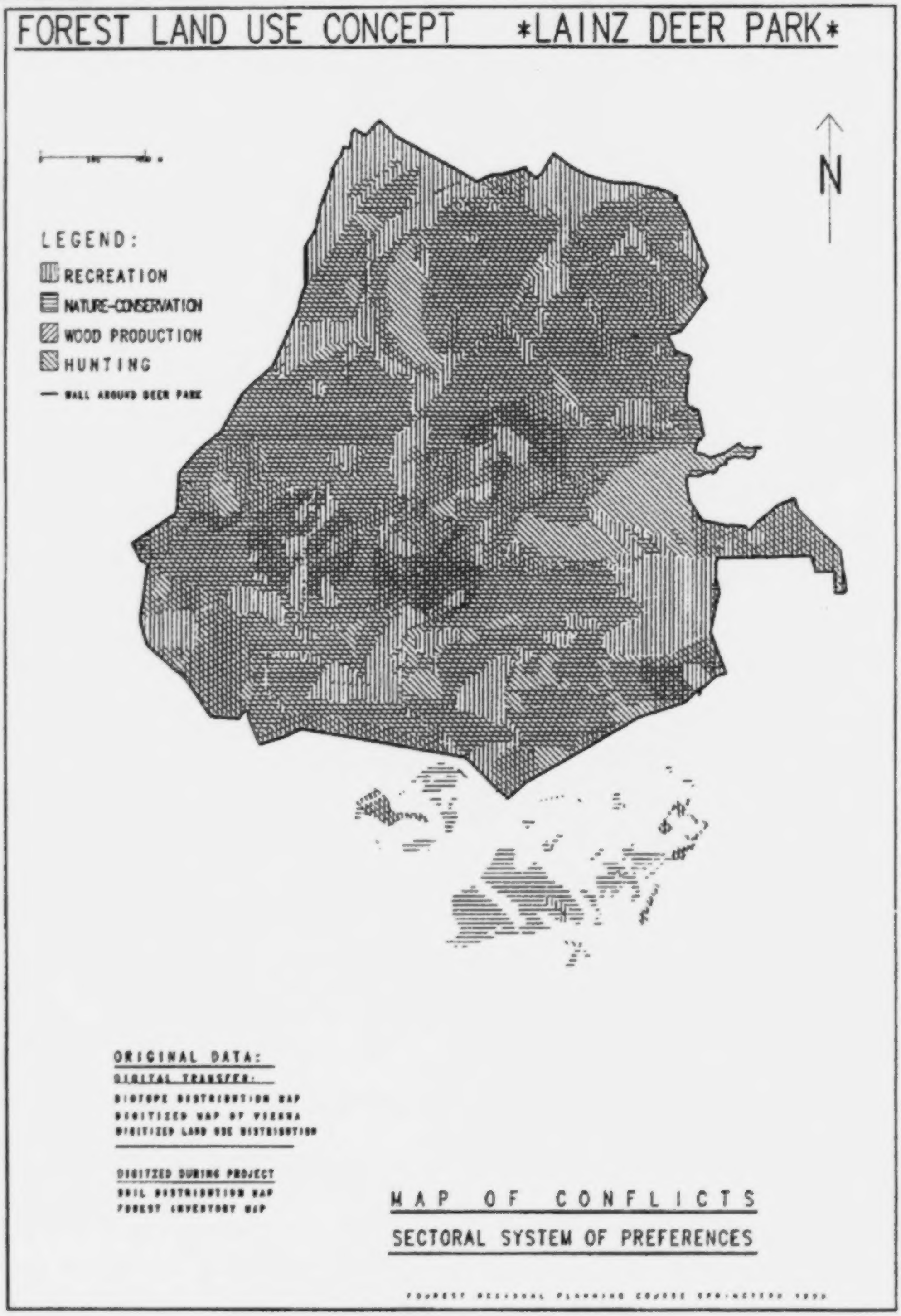

FOREST LAND USE CONCEPT *LAINZ DEER PARK*
N
LEGEND:
▥ RECREATION
▤ NATURE-CONSERVATION
▨ WOOD PRODUCTION
▧ HUNTING
— WALL AROUND DEER PARK
ORIGINAL DATA:
DIGITAL TRANSFER:
BIOTOPE DISTRIBUTION MAP
DIGITIZED MAP OF VIENNA
DIGITIZED LAND USE DISTRIBUTION
DIGITZED DURING PROJECT
SOIL DISTRIBUTION MAP
FOREST INVENTORY MAP
MAP OF CONFLICTS
SECTORAL SYSTEM OF PREFERENCES

Figure 6. Map of Conflicts, Sectoral System of Preferences

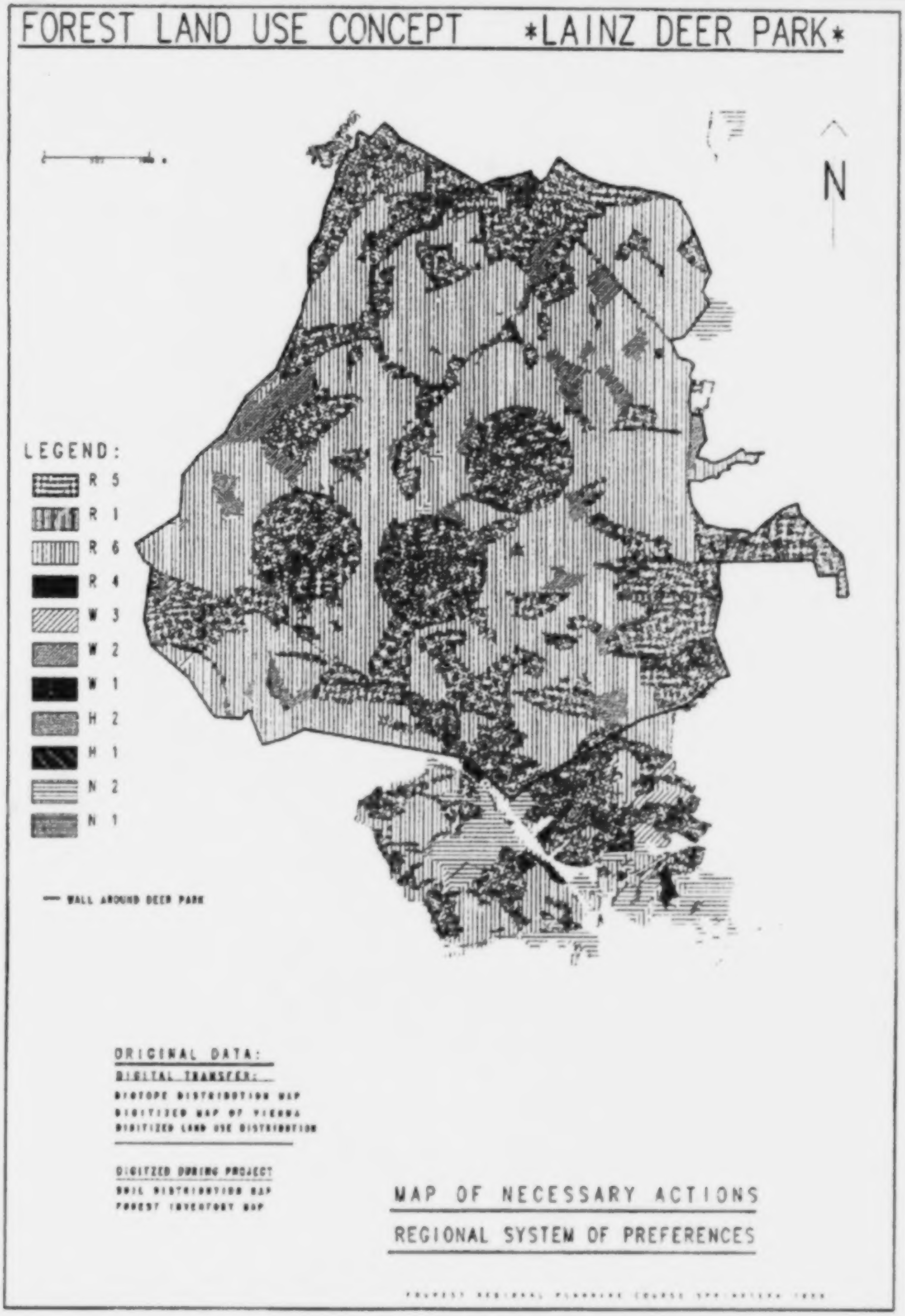

FOREST LAND USE CONCEPT *LAINZ DEER PARK*
N
LEGEND:
R 5
R 1
R 6
R 4
W 3
W 2
W 1
H 2
H 1
N 2
N 1
WALL AROUND DEER PARK
ORIGINAL DATA:
DIGITAL TRANSFER:
BIOTOPE DISTRIBUTION MAP
DIGITIZED MAP OF VIENNA
DIGITIZED LAND USE DISTRIBUTION
DIGITZED DURING PROJECT
SOIL DISTRIBUTION MAP
FOREST INVENTORY MAP
MAP OF NECESSARY ACTIONS
REGIONAL SYSTEM OF PREFERENCES

Figure 7. Map of Necessary Actions, Regional System of Preferences

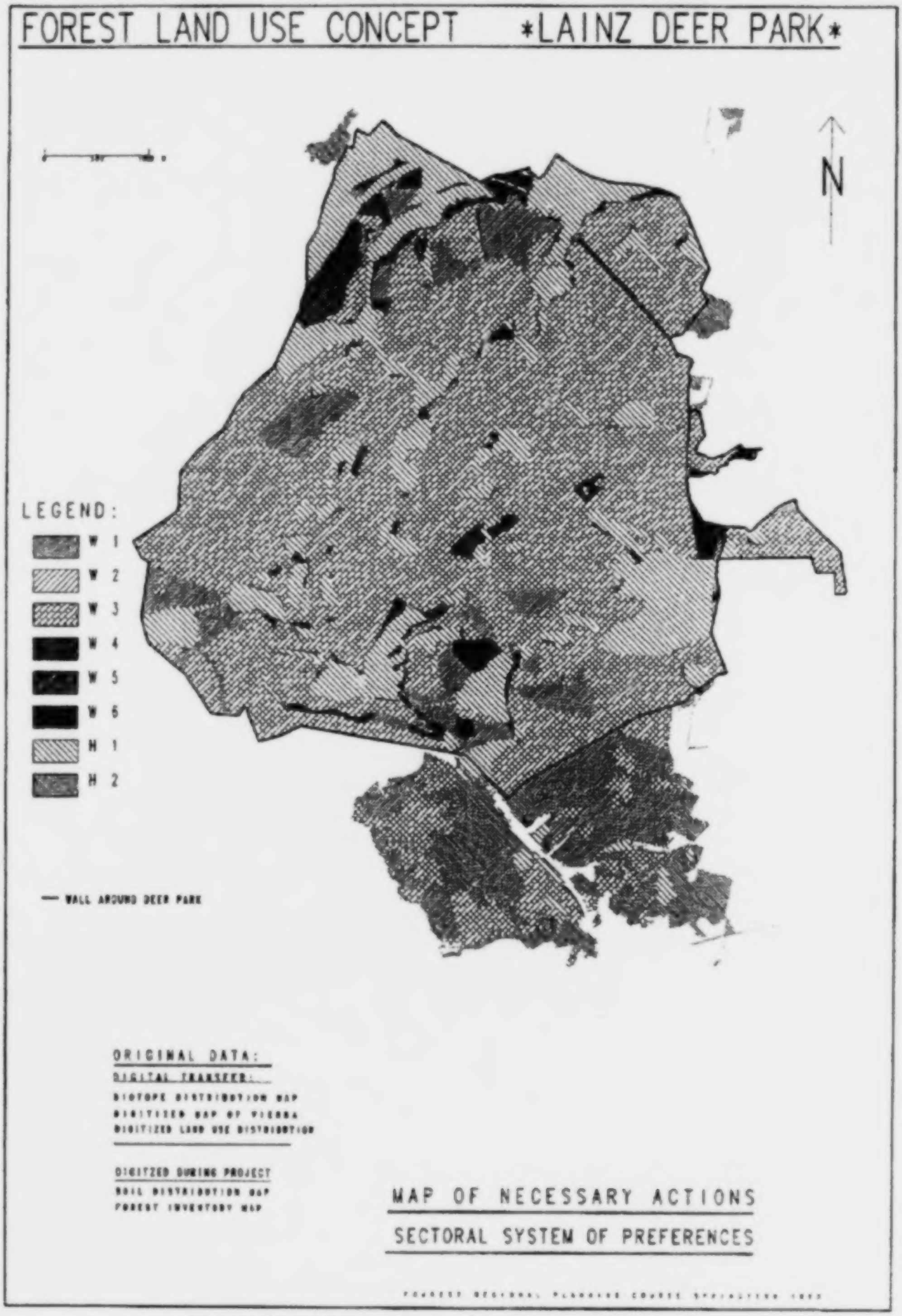

FOREST LAND USE CONCEPT *LAINZ DEER PARK*
N
LEGEND:
W 1
W 2
W 3
W 4
W 5
W 6
H 1
H 2
WALL AROUND DEER PARK
ORIGINAL DATA:
DIGITAL TRANSFER:
BIOTOPE DISTRIBUTION MAP
DIGITIZED MAP OF VIENNA
DIGITIZED LAND USE DISTRIBUTION
DIGITZED DURING PROJECT
SOIL DISTRIBUTION MAP
FOREST INVENTORY MAP
MAP OF NECESSARY ACTIONS
SECTORAL SYSTEM OF PREFERENCES

Figure 8. Map of Necessary Actions, Sectoral System of Preferences

Actions for LLUT *Recreation*

R1: Preservation and enhancement of existing meadows
R4: Preservation and management of existing infrastructure
R5: Current forest stand is the optimum; preserve it
R6: Current forest stand is not the optimum; change management practices

The total cost of implementing each preference system was calculated by summing the product of component areas and the costs per hectare for the various applicable actions.

Figure 9 shows the comparison of costs for the two systems of preferences. The total costs for the realisation of the regional system of preferences are almost double those for the sectoral system. This is due to the large number of relatively expensive actions required for LLUT *Recreaiton*.

Conclusions

The optimization of multiple forest land use will be a major task for foresters in the future. This is extremely evident in a small country like Austria, where it is not possible to assign one type of land use to a large area, such as the national parks in North America. The fact, that in Austria, about 70% of all forest lands are privately owned must be considered in this process. Forest regional planning tries to provide solutions for the conflicts which might arise from the competing interests. As the evaluation and ranking of the different interests depends on the position and views of the evaluator, it is never possible to define a really objective solution.

The concept shown in this paper attempts to consider these facts by demanding a clear definition of preferences at the beginning of the evaluation; these preferences exert a major influence on all succeeding procedures. By presenting the results for two different systems of preferences, the influence of differences can be seen.

Each step of the evaluation is dependent on clearly-defined criteria and so the results can easily be explained and discussed.

The results of this test run have shown that the design method can also be applied to larger areas. Within the next year, a similar evaluation will be performed for the entire Vienna Woods.

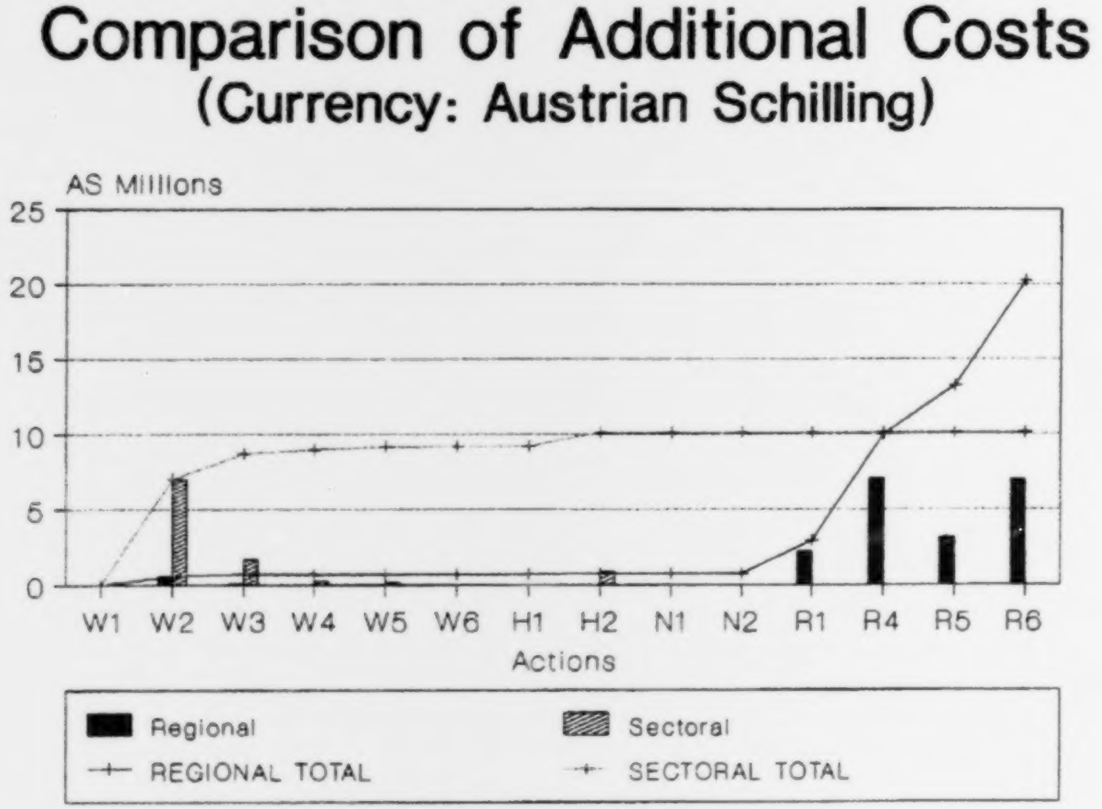


Figure 9. Comparison of Additional Costs

The project served also as a platform for introducing GIS technology to students without prior experience in this field. It was not possbile, and was not intended either, to turn the forest regional planning course into a full GIS basics course, but it was possible to transmit the basic concepts of the technology. The students learned how to define criteria and rules for the management of spatial information in a GIS-processable form. This should be of value later, when it will be necessary for them to cooperate with GIS experts from regional planning departments. Nonetheless, the project also showed that there is a need to introduce GIS knowledge into the forestry curriculum at an earlier stage, so that basic knowledge does not need to be taught during an applied project. The establishment of a GIS center at the Universitaet fuer Bodenkultur in Vienna will help to improve this situation.

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Concurrent Session 9

Techniques - Issues and Concepts

The Provision of General Access to Spatially Integrated Data

Spatio-temporal Analysis Using GIS

GIS and Open Systems Interconnection: Application Layer Protocols

Scanning for GIS Applications

GIS'91

Symposium

Vancouver
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February 1991

The Provision of General Access to Spatially Integrated Data

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Abstract

Many organizations in government and the private sector collect and maintain spatial databases to effectively manage resources within their jurisdictions. Integrating this data from different sources enhances its value to participating organizations. Integrated data enables more informed decisions based on greater knowledge of more varied parameters.

Many issues that need to be addressed to enable the timely integration and distribution of large data sets from data providers to data consumers. This paper examines issues associated with providing the infrastructure necessary to support general access to spatially-related data from multiple sources. The paper also recommends some cirtical actions required in order to succeed in such an endavor.

Introduction

Government and the private sector have a considerable investment in data. The data covers a multitude of uses and is stored both in manual form and on different hardware platforms with their various operating systems and disparate database management systems.

These islands of data contain overlaps, duplications and discrepancies. Major efficiencies can be achieved by gathering the data once and allowing access to multiple users. Productivity and effectiveness are further enhanced when everyone uses the same consistent data set.

Some of the data is spatial. It relates to a location on the earth's surface and it may be defined by a series of coordinates, for example latitude and longitude; or by matching to some characteristic that is itself geo-located, as in a parcel identification number or street address.

Traditionally, both government and industry have been concerned primarily with data from within their own organizations, with limited external linkages. However, both are realizing that the value of their systems is defined not by the hardware or the applications that run on it, nor by the substantially higher costs of acquiring the data itself. The value of the data is the use to which it can be put, and the value increases if it is integrated. The value of the whole is worth more than the sum of the parts.

As greater data integration is achieved within an organization, the need to go outside to obtain and supply information becomes more

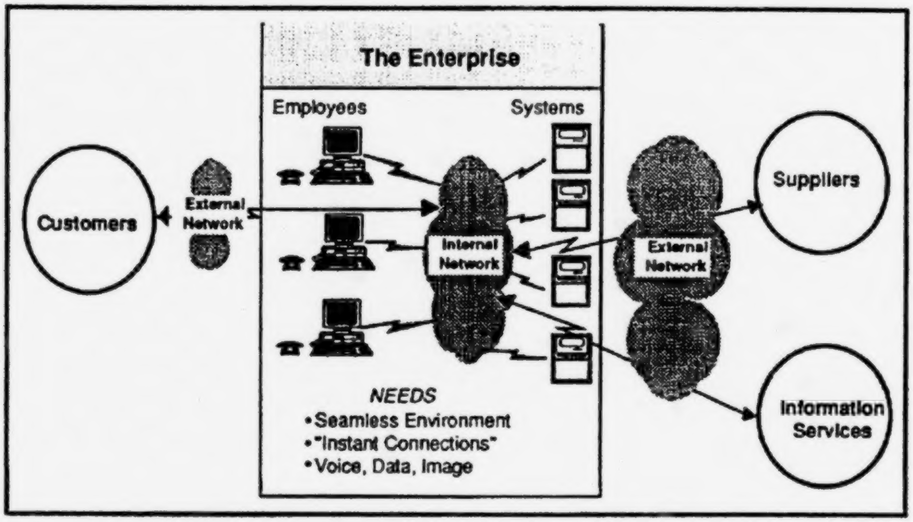

Figure 1.Information Technology Environment of the 1990s Inter-Enterprise Information Networks

apparent. There is a desire to establish inter-enterprise information networks (Figure 1). This is occurring for both spatial and conventional data , as evidenced by the increasing use of electronic data interchange.

This paper examines issues associated with integrating data and presenting it to a variety of users across a geographically dispersed environment. It outlines the actions required to realize the benefits from such an undertaking.

Business Needs

Both government and the private sector are continually faced with the need to provide better customer service and to improve the efficiency of their operations. The private sector must also establish, and maintain, a competitive advantage while differentiating themselves from the competition. Both sectors seek to establish a growth path for their information technology investments. This will ensure they do not find themselves with an outmoded system whose investment value far exceeds its current business value.

When looking at the opportunities for spatial data integration, the issues examined are not confined to geo-related information, they extend to other forms of conventional data. Management Information Systems departments have worked to integrate the data held on their various corporate systems and , in effect , have tried to make a patchwork quilt from islands of automation.

The business case to employ information technology in government or industry has generally been automation of a manual process. This has often been undertaken as a functional, and/or departmental initiative, rather than as part of a larger strategy of changing the business process through the application of technology. The result is often the fossilization of an outmoded business process in a costly system implementation.

For conventional data, the new business need may be met by re-engineering the system, restructuring the database or even starting fresh. Fortunately, we may now be able avoid this by placing a shell around older systems. Existing multi-platform computer systems can hide behind a new, more manageable and flexible system. Older systems do not have be altered and the new user interfaces and data integration can be achieved faster and at a lower cost.

Geographic Information Systems (GIS) have existed for some time as tools for handling spatial data. It is only recently that GIS has emerged as a significant area of technology to be applied to strategic business systems. The number of conferences related to land information and their increasing attendance is testimony to the emergence of GIS as an important tool. However, GIS remains an immature technology; ask anyone who has faced the lack of standards when trying to achieve data transfer between GISs.

The Challenge

More organizations are realizing the importance of using spatial data to effectively manage the resources within their jurisdiction. But they also have to come to terms with the high costs of acquiring and maintaining it. They find that much of the data already exists and ask 'why not buy rather than build?'

The challenge is how to access spatially related data from a variety of sources and successfully integrate it to meet business needs.

The Solution

Information brokerage is a key concept in meeting this challenge. The concept involves taking data from a variety of sources, primarily government, and assembling, repackaging and presenting it to consumers in the form which is of greatest value to them.

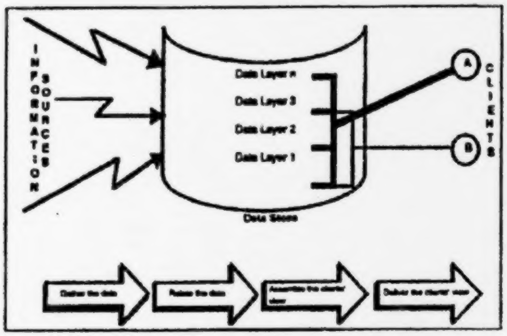

Figure 2. The Information Brokerage Concept

The data is then available as an information service in one of three ways: (1) basic information as a general public offering, such as tourist information; (2) customized for a particular industry, such as Real Estate listings; or (3) customized for a particular client, such as transit information.

If the Information Brokerage concept is locally applied, the amount of data enhancement would vary. It is likely there will be alliances with private sector organizations who are already in the business of repackaging data and who would then serve as information service providers to an information service network.

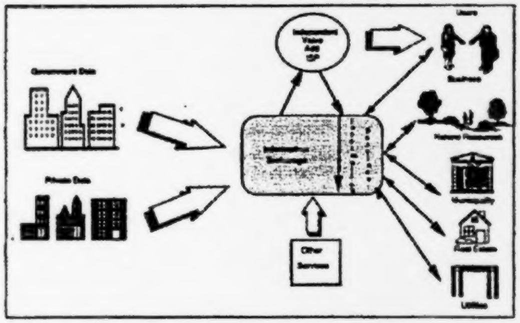

Figure 3. Data Dissemination - Information Brokerage Scenario

Government and industry data would be made available across a public network on a transaction and/or royalty basis. Customer specific data may be made available across a private network.

Government also desires the benefits of data sharing as witnessed by the Corporate Land Information Strategic Plan of the Government of B.C. Both government and industry may require the same infrastructure since their data sharing issues are very similar (Figure 4).

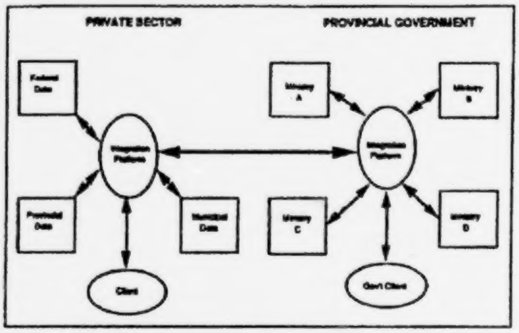

Figure 4. Data Integration Infrastructure Concept

Benefits

Creating an information brokerage as the means to share data has many advantages:

1. It offers universal access as a public service with one stop shopping;
2. The economy of scale allows investment in the necessary infrastructure for ubiquitous access and in the leading edge technologies for the data delivery;
3. Data can be integrated and customized before delivery for customers who are unable, or unwilling, to do it in-house. There is an opportunity for organizations to add value and participate as information service providers to a wide client base across the network;
4. Central management allows for simpler data management, centralized billing and royalty collection; and,
5. The government can be insulated from the business of data dissemination.

Without such an information brokerage, there will likely be a series of retail outlets reselling certain data to limited users. This will not require the significant investment in infrastructure required by the Information Brokerage and will allow more participants. However, it will present some problems:

1. There will be costs to government and overheads associated with maintaining distribution to multiple outlets and the related billing and royalty collection;
2. There will be customer confusion as to which outlet has what data with limited access and only limited data integration before delivery. This will be disadvantageous to smaller clients; and,
3. There will be a complex data management problem with multiple copies of data sets being held by retailers.

Issues

GIS is one of many tools that will be used to meet the challenge of integrating spatial data. There are a number of technology-related issues to consider in establishing any form of Information Brokerage. These include:

1. GIS - The key to relating the data by keying to its geo-location. GIS must be used for the management, analysis and graphical presentation of the spatial data.
2. Object Oriented Languages - How can this emerging tool be used for application development and the management of data as objects on distributed databases? The establishment of data repository and data management tools is required to allow access to constantly changing independent data sources.
3. Surround Technology - How to employ this for system integration by encasing existing systems housing conventional attribute data?
4. Presentation - How to integrate multimedia and apply the graphical environment in superior user interfaces?
5. Architecture - Performance and cost will determine the location of the data and its processing. This will change as both hardware and communication costs fall.
6. Communications - It will be essential to have a high bandwidth infrastructure available, at reasonable cost, suitable for large spatial data sets and associated graphics. Sophisticated real-time network management will be required to support the distributed environment.

There are also the normal data issues including:

1. Accuracy - Not simply the accuracy of one data set in all its forms, but the accuracy of a combined data set and how that is represented.
2. Maintenance - Who maintains the data and how is that reconciled with user needs when the data concerned is an integrated set?
3. Timeliness - Speedy delivery of data is especially important where its temporal nature is significant.
4. Ownership - Who owns the data when it has been integrated into a new product? What are the copyright and royalty implications and requirements?

Unfortunately, some of the most difficult issues are organizational, such as:

1. Access - Data is held by a variety of federal, provincial and local government organizations as well as private sector companies. There are often inconsistent policies regarding public access to the data and often no policy at all.
2. Risk Management - How to reduce risks to acceptable levels that allow sufficient returns to justify the significant industry investment required to establish the necessary infrastructure.
3. Legal - Who is liable for errors found in products based on multiple source data? What legal protection is available to the user and vendor?
4. Administrative - How to effectively manage billing and royalty collection for use of brokered data and integrated data products.

Conclusion

Fortunately the skills to solve many of the technical issues exist and we are starting to see a desire to tackle some of the organizational ones. These issues can not be resolved by one organization working alone.

There are already a number of successful, regional multi-participant projects. These are based on a common need to establish a landbase on which the various local organi-zations can base their own data. Organizations must look further than this and establish the mechanisms to share, and use, the vast quantities of existing spatial data.

To accomplish this, organizations need a new type of multi-participant project. It will require partnerships between companies expert in the various technology areas and between private sector distributors of the data and the government , as the principal data supplier.

Actions Required

The government can not be expected to resolve all the issues discussed in this paper. However, there must be a willingness from all levels of government to work with the private sector to solve these problems and realize the benefits together.

Notable critical success factors are:

- Joint leadership and participation in the information brokerage;
- Clear and consistent policies on access to public data, costs, copyrights and royalties that encourage the required private sector investment ; and,
- The establishment and promotion of spatial data interchange standards.

Admittedly, there will be a high cost attached to establishing the necessary infrastructure. But, this is an investment with considerable future benefits. Few organizations have the vision and skills to meet the challenge. Those that do will have established the means to achieve greater efficiency in both government and industry. They will also have confirmed a leadership position for Canada with its attendant competitive and export advantages.

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Spatio-temporal Analysis Using GIS

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Abstract

The majority of commercially developed GIS assume a time static spatial database. The bulk of all real world GIS applications, however, do contain spatio-temporal variability that may be of importance when preparing routine reports or conducting spatial analysis. This paper will introduce and examine a number of spatio-temporal issues which GIS should ideally be able to handle. A taxonomy of spatio-temporal applications is proposed.

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GIS and OSI Application Layer Protocols

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Abstract

Within the world of data communications, an internationally-accepted standard has been formalized by the International Standards Organization. The Open Systems Interconnection basic reference model (IS 7498) is the standard specification paradigm for describing network architectures and distributed systems. Currently, ISO is standardizing several data management and transfer services and protocols within OSI's application layer that will directly impact the continued development of Geographic Information Systems. Since the combination of GIS and Data Base Management Systems provide organizations with spatial data management services, how might OSI standardize their union within the context of Spatial Data Base Management Systems (SDBMS)?

There are at least three ways in which OSI can standardize the management and transfer of spatial data.

Firstly, OSI is an open standard upon which open systems can be specified and understood. The standard is well entrenched within the telecommunications industry and is 'spoken' by many computer networking specialists. The OSI model itself, then , is a standard protocol facilitating the design and specification of open systems.

Secondly, related OSI standards are useful in the specification of data transfer protocols between heterogeneous Geographic Information Systems. To date, the Province of Ontario and the Canadian Hydrographic Service have produced two such specifications within the OSI paradigm, MDIF and MACDIF, respectively, using a formal description technique known as the Abstract Syntax Notation - One (IS 8824).

Thirdly, and most importantly, OSI application layer data management, access and transfer services and protocols will give rise to standard implementations of SDBMS and other distributed data base applications accommodating very large data banks such as British Columbia's spatial data base. As it will be shown, the management of B.C.'s spatial data base is both logically distributed across many ministries and physically distributed across many dissimilar computers and many similar data management application systems such as GIS and DBMS.

In order to justify the assertions made above, this paper will present a brief introduction to OSI, will explore the relationship between DBMS and SDBMS, will provide a contrived example of a spatial data base and it's distributed implementation, will describe the integrity-preserving two-phase commit protocol and will finally conclude by relating the discussion to the results produced by the Ministry of Crown Lands during the last year.

OSI: An Introduction

The Basic Reference Model of Open Systems Interconnection (IS 7498) is an abstract model of a functional computer network. OSI is the only universally acceptable standard for specifying the behavioural properties of network architectures and distributed systems. The model and its related standards define precisely the manner in which two computer systems communicate with each other without specifying detailed implementation issues like the physical medium of exchange (e.g., coax cable versus shared memory versus magnetic tape) (Judge, 1988). The OSI model decomposes a conversation between two computer systems into seven distinct layers. Of these seven layers, the top four are collectively referred to as the application layer while the bottom three are collectively referred to as the network layer. Figure 1 presents a simplified illustration of the abstract OSI model.

In this simplified illustration, the boxed objects correspond to individual layers. Each layer may be recursively subdivided into sublayers. Regardless, each layer or sublayer offers services to the layer above via its protocol entities. Each protocol entity is confined to a single layer and provides a set of services to its users and its peers. These services define the external behaviours of the protocol entity and constitute its service specification. As far as a user is concerned, each protocol entity can be regarded as a black box whose internal behaviour is hidden from view. The implementor, using the service specification as a contract, provides a conforming implementation of the entity's internal behaviours according to the rules and guidelines set out in a protocol specification. Those readers familiar with object-oriented implementation environments like Smalltalk, Actor and Windows 3.0 will notice many similarities between OSI and an object-oriented paradigm. Perhaps OSI or one of its formal description techniques will eventually facilitate the standardization of an object-oriented paradigm.

Examples of application layer protocols currently being standardized by the Institute of Electrical and Electronics Engineers and the ISO respectively include the Portable Operating System Interface Environment (POSIX) and the Structured Query Language (SQL). Both POSIX and SQL are similar in that each provides its user with a common interface to operating system services and data base management system services.

In addition to SQL, an OSI working group within ISO is standardizing other application layer protocols related to the management and transfer of data within a distributed environment. In the true spirit of OSI, this working group is itself distributed around the world. In Canada, the Canadian Advisory Council (CAC) is the national group that monitors, contributes, and votes on the international standards being developed. Although the Canadian Standards Association is responsible for approving national standards, most of the various committees within the CAC working group are co-ordinated and thus fulfill both roles.

The Relationship Between DBMS and SDBMS

Generally-speaking, data base management systems facilitate the sharing and storage of data within a secure and predictable environment. In order to provide such an environment, data base management systems employ synchronization mechanisms that serialize data base transactions into logical atomic units of work. Within a seemingly single step, these transactions can be either rolled back or committed permanently to secondary storage. As an example, consider the frequently executed banking transaction that debits funds from one account and then credits these funds to another. Not only do these separate events need to be serialized, they need to be grouped into a single atomic transaction. For the entire transaction to succeed, each individual event must succeed; otherwise, the state and integrity of the data base is unpredictable. For this reason and others, it is useful to classify SDBMS as evolved descendants of more general and traditional DBMS. In other words, a SDBMS is a DBMS and more.

Traditional DBMS are routinely fitted with simple data types like numbers and characters, although some extend this range by including abstract data types like money, date and time. SDBMS, on the other hand, further extend this range of inherited data types to include spatially-oriented abstract data types like points, lines and polygons. Unlike traditional DBMS, standard 'off-the-shelf' implementations of spatial data base management systems are virtually unavailable. As a result, existing spatial data base management systems and their prototypes are non-standard implementations of integrated computer systems resulting from isolated efforts put forth by GIS vendors and those consultants within the computer industry that refer to themselves as system integrators.

The Hypothetical Design of a Spatial Data Base

Given an increased awareness of environmental issues, the intrinsic utility of digital data stored within spatial data bases is well established. It is estimated that within British Columbia alone, the volume of spatial data owned and managed by the provincial government ranges in the hundreds of gigabytes. For reasons other than its extremely large size, the management of British Columbia's spatial data base is spread across several ministries and many heterogeneous computer software and hardware systems.

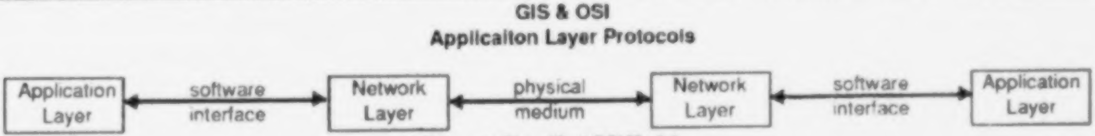

Figure 1: Simplified OSI Model

Therefore, spatial data bases like British Columbia's stand to benefit significanlty from networked applications such as distributed data base management systems.

In order to illustrate the relevance of distributed data base management systems to spatial data bases, a hypothetical example of a mineral claims spatial data base is presented. The conceptual mineral claims spatial data base is described in terms of a uniform homogeneous relational data model extended to support complex objects. This object-oriented extension to the relational data model described by Gardarin (1989) is compatible with the universal relation of Ullman (1982). Subsequently, the conceptual mineral claims spatial data base is modelled in Figure 2 as a single relation.

ClaimNo.	Owner	RecordDate	SketchMap
01	"Tom"	901231	
02	"Bob"	910101	

Figure 2

For simplicity's sake, the universal relation of the mineral claims spatial data base has only five attributes associated with it. The values of these five attributes are characterized by the following abstract data types: ClaimNo, Owner, RecordDate and SketchMap. Although considered esoteric by the uninitiated, the design and specification of abstract data types (ADT) is a popular data abstraction technique employed by computer scientists during design of data base schemas and network architectures. In fact, the following paragraphs pertaining to ADTs nicely complement the discussion thus far as ADTs and OSI exemplify two of the most powerful description techniques known to computer science: abstraction and decomposition (Wulf et al., 1981).

Given the data in Figure 2, let us compare the two data types SketchMap and Owner. While the SketchMap ADT appears to descend from a geometric data type, the Owner ADT appears to descend from a character string data type. Rather than decompose the SketchMap ADT into its apparently obvious constituents, let us decompose the Owner ADT by focusing upon a possible implementation.

Although many computer programming languages provide built-in support for the creation and manipulation of character strings of varying length, Pascal does not. Pascal programmers then are forced to implement character strings as ordered collections of individual objects whose values are characterized by the primitive, built-in data type Char . The Pascal programmer must provide translation algorithms between the primitive operations associated with the Char data type and the abstract operations associated with the constructed string data type.

A Hypothetical Distributed Implementation of a Spatial Data Base

As illustrated, Figure 2 achieves the data management goal of physical data independence by preserving both network and location transparency. Whether or not the data is physically distributed either horizontally or vertically is irrelevant to the user (IBM Technical Report). However, since we are interested in distributed systems, this section of

ClaimNo.	Owner	RecordDate	RobId
01	"Tom"	901231	robId01
02	"Bob"	910101	robId02

GobId	SketchMap
gobId01	
gobId02	

RobId	CobId	GobId
robId01	cobId01	gobId01
robId02	cobId02	gobId02

Figure 3: GIS and OSI Application Layer Protocols

```
Def twoPhaseCommit( self, aProposedTransaction,
theTimeOutPeriod ) {

/* firstly, decompose the proposed transaction into its
GIS and DBMS subtransactions */

proposedSubTransactionA := theGISPart (proposed
    Transaction );
proposedSubTransactionB := theDBMSPart(
    proposedTransaction );

/* secondly, simultaneously ask each system to vote
    upon their respective transaction */

insertVote( theBallotBox, sendBallot( GIS,
    proposedSubTransactionA )) |||
insertVote( theBallotBox, sendBallot( DBMS,
    proposedSubTransactionB ));

/* thirdly, check the ballots and react accordingly */

if NO_VOTE in theBallotBox then
        sendAbortTransaction( GIS,
            proposedSubTransactionA ) |||
        sendAbortTransaction( DBMS,
            proposedSubTransactionB );
else
        commitResults := sendCommit( GIS,
            proposedSubTransactionA ) |||
                sendCommit( DBMS, proposed
                SubTransactionB );
        if any( commitResults ) == FAIL or the Time
                Out Period == 0 then
            sendRollBack( GIS, proposed Sub
                Transaction A ) |||
            sendRollBack( DBMS, proposed Sub
                TransactionB );
        else
            sendUpdateTransactionLog( self,
                proposed Transaction );
        endif;
endif

/* end two-phase commit protocol */
 }
```

Figure 4: An implementation of the two-phase commit protocol

the paper describes a distributed implementation of the conceptual data base illustrated in Figure 2.

In essence, we have already applied horizontal distribution to our solution. As you will recall, this paper began by investigating the relationship between distributed data bases and the spatial data base of British Columbia. We are now focusing upon a single map theme: mineral claims. As it was stated earlier, British Columbia's spatial data base is distributed across several ministries. In order to accommodate this requirement and distribute the rows of British Columbia's spatial data base across several ministries, we can add the data type Ministry to our physical data base and create a corresponding view that hides the horizontal distribution from the conceptual data base and it's users. We can horizontally distribute the rows of the mineral claims spatial data base by adding another data type, say, Mining Division, thereby facilitating the distributed management and administration of mineral claims geographically within the province.

More interestingly, we can also vertically distribute the columns of the conceptual spatial data base across heterogenous data management application systems like GIS and DBMS. As illustrated in Figure 3, the columns of the mineral claim records are vertically distributed. In this example, the data types ClaimNo, Owner and RecordDate are managed by a DBMS while the SketchMap is managed by a GIS. This example of vertical distribution corresponds to a common DBMS integration strategy employed by several GIS vendors in their attempt to meet the higher-level requirements of the conceptual data base and its users.

In order to manage the vertical distribution of the implementation, we have added several additional attributes to the physical data base. The attributes characterized by the data types RobId, GobId and CobId, invisible to the conceptual data base, correspond to record object identifier, graphical object identifier and connection object identifier respectively. In the example, each one-to-one relationship between a record object and a graphical object is represented by a connection. In order to preserve the integrity of the distributed spatial data base, we must preserve the integrity of the connections. The management of the connections then must be governed by a standard protocol.

The Two-Phase Commit Protocol

The two-phase commit protocol is so named because of the 'voting' phase followed by the 'decision to react accordingly' phase. The co-ordinator (e.g., the distributed data base manager) asks each participant, the GIS and the DBMS, whether or not they are willing and able to carry out their respective sub-transactions locally. If either system responds with a no vote, the proposed global transaction is aborted and the user will have to try again later. On the other hand, if both participants vote yes, then each participant is commanded to execute their respective sub-transaction locally. Should either participant fail or not respond within a prearranged time-out period, both systems are commanded to roll back to their prior state.

For reasons unknown, the two-phase commit protocol is not the subject of any known international standard. However, several manufacturers of DBMS have implemented it's precursor. The following computer program listing, written in an extended version of Actor 3.0, is an object-oriented implementation of the two-phase commit adapted from Ullman (1988). For this example, Actor 3.0 has been extended with a parallel operator, |||, meaning that each operand (e.g., message) should be broadcast simultaneously over the network.

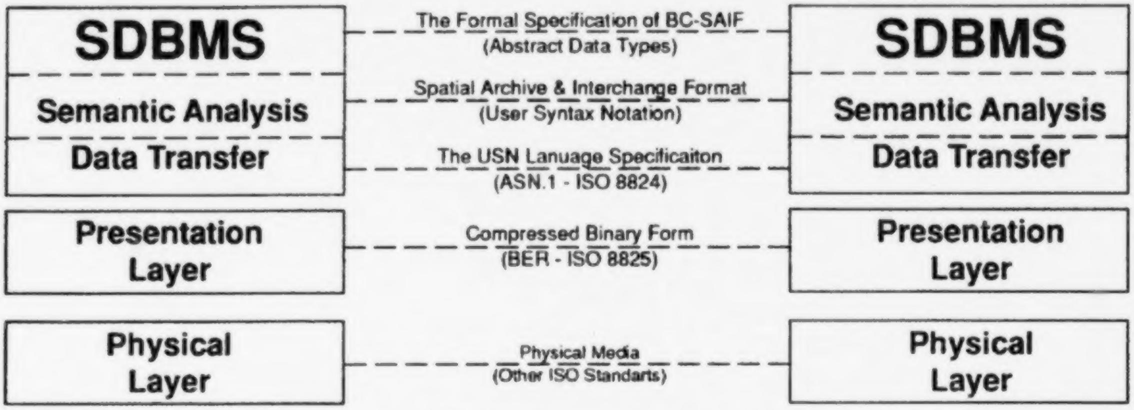

Figure 5: The Emerging Network Architecture of B.C.'s distributed Spatial Data Base
This architecture is incomplete as data management and security protocols are excluded.

In order to illustrate the effects of the two-phase commit, the following scenario is presented. Suppose a user accessing the spatial data base via a GIS wishes to delete a mineral claim while at the same time another user accessing the same mineral claim via another GIS or a DBMS is attempting to change it. Given that a distributed data base manager serializes these discrete events, then the two-phase commit protocol guarantees that either the change takes place and the delete does not or that the delete takes place and the change does not. In either case, the distributed data base manager preserves data integrity leaving the spatial data base in a consistent state.

Conclusion

Towards the implementation of British Columbia's spatial data base, the Ministry of Crown Lands has broken some new ground. An open network architecture is emerging. It is intended that this technical architecture will some day support British Columbia's spatial data base.

The emerging architecture is illustrated in Figure 5. Based upon a layered approach, the architecture acknowledges existing ISO standards, including the OSI model itself. Within the architecture, only the application layer introduces protocols that have yet to become national or international standards. Other potentially relevant standards either established or adopted by OSI include protocols for file transfer, access and management, remote data base access, virtual terminal emulation, networked and distributed operating systems, a message handling system, a reference model for data management, an information resource dictionary system, and a directory system.

For reasons that are more human than they are technological, it is predicted that several years will elapse before the technical architecture described here or its successor is standardized within British Columbia, let alone the rest of Canada. Standards like OSI are paramount to the successful implementation of British Columbia's spatial data base. Without these standards and the open systems they give rise to, organizations like the government of British Columbia will endlessly spend taxpayer's money upon computer systems that are both difficult if not impossible to maintain and enhance in the face of an ever-changing computer technology.

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Scanning for GIS Applications

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Abstract

Due to the recent advances in scanning, the technology has become a credible alternative for both CAD and GIS applications.

A major misconception is that scanning produces either a raster or a vector file which is made up of broken line segments with all elements on one layer. If utilized properly, a scanning system can produce a GIS-compatible file that is layered, feature coded or separated, and made up of continuous lines and ASCII text strings which can be utilized as centroids or labels for polygons.

This scanned end product, if prepared correctly, can be ready for import into a GIS for cleaning and building of topology. Some scanning service companies are now offering data that is 'GIS ready' in the desired format.

Introduction

With increased interest in GIS for a number of applications, the requirement for a fast, cost- effective and accurate method of data loading has become a real issue in the minds of many users.

It is not the intention of this paper to convince the reader that scanning is the total solution for all GIS data loading. The present status of scanning in general will be examined and the pros and cons of the technology and its effectiveness for GIS will be explored.

It is always interesting to see a company or government office purchase a GIS. Once this new acquisition is in place, the huge task of loading all of the desired data becomes only too real. With the usual methods such as digitizing, this task can often become overwhelming. New advances in scanning allow the technology to be a viable method of data loading for GIS applications.

Background of Scanning

Not too many years ago, scanning was looked upon in many circles as a method of conversion without merit. This was simply because the raster format produced by scanners was not revisable, nor compatible with the majority of vector-based CAD software formats.

Recently, scanning manufacturers have found methods to convert raster information into vector line work. This created a beginning point in providing compatibility with vector-based software and as a viable alternative to labour-intensive manual digitizing.

Present Scanning Technology

Today, there are several manufacturers of scanning hardware and software. As in any industry, there are high-, medium- and low-end products available in the scanning market. These systems are available on various platforms.

Higher-end products offer some impressive capabilities in automatic vectorization. This comes with a price tag that could choke the healthiest of budgets.

Medium-priced scanning products offer vectorization, often with fairly successful results. The trick with any system is to determine the amount of clean-up that is required.

Scanning systems at the lower end of the market tend to offer scanners that take longer to rasterize a document. Most of them simply offer raster tracing in a CAD environment, rather than automatic vectorization. However, some vectorization is available even with this lower end product line.

Products at all levels of the market have their own merit on a cost versus performance basis. It's true that you get what you pay for. Sometimes it simply depends upon your budget.

Evaluating Scanning for GIS Applications

Suitability of Scanning for GIS

It would appear that the suitability of scanning for base mapping purposes is largely hinged upon the opinion of the people involved , regarding the importance of accuracy in the particular project. Another major factor is the accuracy of the source maps available.

The reality of scanning capabilities is that the technology can recreate a source map in a digital format with a high degree of accuracy, depending upon the system and resolution used. However, scanning can only recreate the same accuracy as was present in the original source map. The argument which prevails, therefore, is that it makes no sense to perpetuate the same errors which have been created over the years in creating and updating that map. This argument has merit, especially when poor practices in maintaining control have been used on original source maps, particularly in municipal or cadastral applications.

The solution to this problem in many cases is in the use of 'rubber sheeting' or 'linear/non-linear transformation' capabilities in many GIS packages. If some control points can be established, such as survey monuments, the rubber sheeting capabilities can be utilized to greatly increase the accuracy of the base map. This same technique can be used in both resource and legal mapping applications to enhance the digital end product of scanning.

If the GIS user does not feel that these adjustments adequately enhance the scanned file for base mapping, the technology can still be used for loading information which is not as dependent upon a precise location, such as contours, text for lot dimensions, signage, water and sewer information. This information can then be merged as levels over the existing base map.

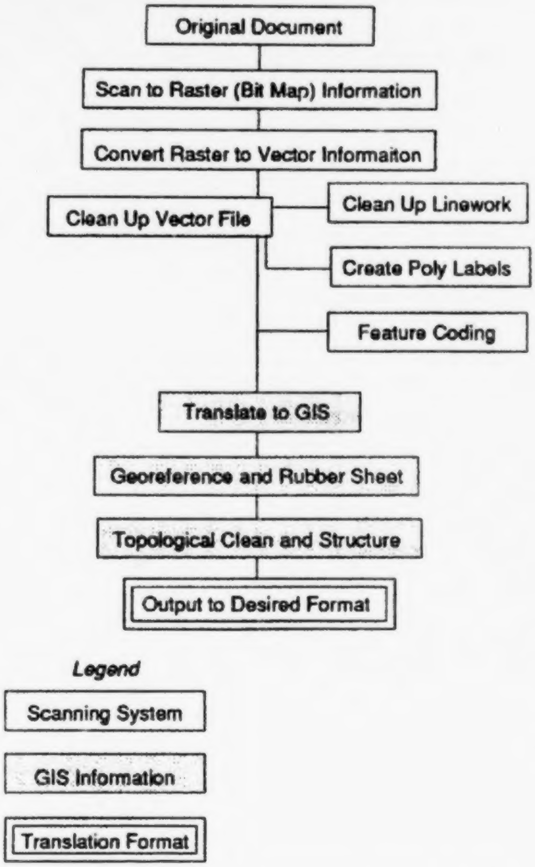

Figure1. Typical Scanning Process for GIS Applications

Benefits of Scanning

Scanning offers GIS users some impressive benefits in data loading.

Turn-around Time

Automatic vectorization found in many high-end scanning systems decreases the amount of interactive work required by an operator. This allows scanning to accomplish the same work in a fraction of the time as manual digitizing or direct input. One example is a project,done by SCAN Conversion Services Inc., for a local municipality. The GIS coordinator had estimated the project to require approximately one and one half years to complete the conversion of several hundred contour and legal maps using their own resources. The project was completed in three months using scanning technology.

Price

Depending upon the source material available, scanning can convert maps at a fraction of the cost of other methods.

Because this is so dependent upon the condition of the original map, it is important to always do a scanning test to determine all aspects of the conversion, including price considerations. Often, maps which are in poor shape can still be processed at less cost than other methods. A considerable savings can be realized by processing only the features in a map that are required. Many think that scanning must process all elements in a map; this is not the case. One can pick and choose amongst the desired features.

Accuracy

Scanners at the higher end of the market are able to provide a high level of accuracy. Scanning at a resolution of 500 dpi, some scanners are able to recreate a map accurate to .04% of the original drawing.

To ensure that the highest level of accuracy is achieved, the automatic vectorization of some scanning systems process a line by vectorizing the precise centre of a raster line. This is much more accurate than digitizing, where determining the centre of a line is left up to the steadiness of an operator's hand.

Contract Work versus In-House

Perhaps the very first question which an organization must ask itself is, "Can we do the scanning in-house?".

In-House

For organizations with adequate resources to carry out this task in-house, the following are considerations which must be addressed:

1. Is the organization willing to invest in the considerable training and learning curve that is associated with scanning technology ? Unfortunately, a scanner is not a black box which spews out a perfect CAD or GIS product. There is a certain finesse that is required to make the system perform at its peak.

2. In addition to the cost of the hardware and software, the maintenance and constant upgrades of the system must also be kept in mi nd. As scanning progresses, software upgrades are frequent, mandatory (so as not to be left behind) and very expensive.

3. When the scanning task is completed, will the equipment be a white elephant which has lost a large percentage of its original value?

Contracting Services

If an organization cannot justify these three basic criteria, the task of selecting a service company begins.

When choosing such a company, the following may be helpful hints in making the right choice:

1. The company's reputation;

2. What is their ability to second-guess your technical requirements?

3. It is highly advisable to do a test. The company with the best price may not be capable of fulfilling your technical or time frame requirements.

4. Ask the potential service company what type of source material will be necessary to provide the best results in terms of accuracy, cost and turn-around time.

In many cases the answer is obvious, due to resources. The contracting of a service company is therefore the logical choice.

Creating the Best Scanned Product

Regardless of whether an organization does its scanning in-house or with a service company, the following points may help in achieving the best results in accuracy, price and turn-around:

1. Determine your requirements in advance to avoid confusion. Feature coding, representation of data, what portions of work are best done by the scanning company and those best done in-house. For instance, key punching of attributes, symbology, building of topology.

2. Do a test to streamline those requirements and establish efficiencies.

3. Select the best source material available. As a rule of thumb, the best results in scanning are produced from material with the following characteristics:

   a. Clean line work - The less background or fuzziness present in a source map, the easier it is for the scanner to interpret the information. Mylars or some other stable media is preferred to produce the most accurate results.

   b. Intersecting lines - The more lines that intersect in a map, the higher the chance that the automatic vectorization may break the line or continue along on the wrong line. If this is widespread, more clean up will be required, which affects the price of the conversion.

   c. Line types - A clean solid line is the preference of most scanners. Generally, any dashed or dotted line will either require tracing or repair. The clean up software used in conjunction with scanning can quickly repair these lines to a continuous solid line very efficiently. The end product will always be excellent (depending upon the operator), but the price will be affected somewhat.

   d. Separation of features - One method which has been found to be effective is to separate certain features onto different source maps.
      1. Forest polygons
      2. Planimetric
      3. Contours

This eliminates the number of intersecting lines if a number of features are required on a map.

Energy Mines and Resources, Mapping and Remote Sensing Sector in Ottawa has utilized this in the scanning of 1:250 000 and 1:50 000 NTS maps with considerable success.

Conclusion

If any conclusions can be made regarding scanning, it is that, for GIS applications, it can be very effective and useful. The catch is that it must be approached properly. One cannot expect a machine to take a horrible mess and turn it into a thing of beauty without some form of human interaction.

The cost of contracting out scanning can certainly rival digitizing. However, in terms of turn-around time, there is no other loading system which can compete with scanning.

Concurrent Session 10

International Forestry Applications

Nepal 2000: A GIS Evaluation of the Major Land Resources

Quantitative GIS Analysis of the Forest Resources in a Mountain Watershed in Nepal

GIS for Assessing Habitat and Estimating Population of Red Pandas, Langtang National Park, Nepal

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Symposium

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Nepal 2000, A GIS Evaluation of the Major Land Resources

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Abstract

Between 1979 and 1985, a CIDA-sponsored integrated land resource inventory was conducted for all of Nepal at the scale of 1:50 000. The available data on agriculture and forestry were converted into a GIS system and a spreadsheet model was developed to evaluate the food, feed and fuelwood surplus/deficit situation for each of the 75 districts in Nepal. Using current growth rates, the sustainability of the major resources was evaluated and different development scenarios were made using GIS techniques for the year 2000. The GIS model allows us to determine the magnitude of the resource problem, to evaluate the consequences of different development scenarios, and to propose alternatives to avert a sustainability crisis. The analysis includes an assessment of the overall combined resource status for 2000, development scenarios for fuelwood and a sensitivity analysis of key variables. The spreadsheet-GIS model represents a new way to understand and evaluate natural resources at the national level.

Introduction

The land resource base that supports the basic food, feed and fuelwood needs of the Nepali people is very limited. The country's distinct monsoon season, pronounced dry season, adverse topography, and poor slope stability all contribute to making improvements in biomass production and resource sustainability an onerous challenge.

Between 1979 and 1985, the Land Resource Mapping Project was carried out; this included the systematic inventory of all agricultural and forestry resources in Nepal at the scale of 1:50 000 (LRMP, 1986). This provided the first consistent national resource inventory data base for agriculture, forestry, land capability, landforms, soils and geology for the country. A preliminary evaluation of the data by Shah et al., (1987) indicated that GIS can play a key role in developing a dynamic resource evaluation model which be used to provide a resource overview for national land use planning (Schreier et al., 1989 & 1990).

A spreadsheet model, linked to a Geographic Information System (GIS) was developed and relevant resource data were evaluated quantitatively for all 75 districts in Nepal. The aims of this research were:

1. To evaluate the resource sufficiency for food, feed and fuelwood for the current population in all 75 districts;
2. To evaluate the combined resource status for the year 2000;
3. To determine resource development scenarios relating to forestry and fuelwood production; and,
4. To carry out a sensitivity evaluation to identify what variables have the greatest influence on the balance sheet calculations.

Method

The LRMP data were converted into a spatially related GIS data base and a spreadsheet was linked to the GIS system. For each district, a supply and demand balance sheet was developed and the consumable food, animal feed and fuelwood production was calculated. Eight major staples were included in the food model; three forest types, shrub, grassland and four forest maturity classes were used in the fuelwood model, and forest and agricultural production was used in the development of the animal feed model.

Population census and animal inventory data collected during the LRMP survey (LRMP, 1986) were used to calculate the food, feed and fuelwood demands.

The supply and demand balance sheet calculations were simplified to facilitate GIS representation of all districts in the following three categories:

1. Supply exceeds demand by more than 20% (surplus)
2. Supply and demand are within ± 20% (sufficiency)
3. Demand exceeds supply by more than 20% (deficit)

A brief summary of the details of the model are provided in the following three sections. Trade in food, feed and fuelwood was not included in the model because trade data are not available and because Nepal is characterized by a subsistence economy.

Evaluating the Food Resources

The following key variables were used in the food sufficiency calculations: mapped aerial extent of the agricultural land, crop intensity, dominant crop rotation for eight major staples, and average yields for each crop for every district according to physiographic position. Adjustments were made for non-cultivated inclusions in agriculture, losses due to seed retention, wastage, milling, and uses for animal feed. Yields were also adjusted to account for differences in production with respect to the sequence in the rotation. Where irrigation water is available, agriculture is usually dominated by triple annual crop rotations in all of the climatically favourable areas. Double crop rotations are the dominant agricultural land use when irrigation is not possible. Eight staple crops were considered in the rotation and the yield data from the economics report (LRMP, 1986) and from interviews were used to arrive at production rates. The total production of food was then calculated for each of the eight dominant crops using the following formula :

$$Y = [(X_D \cdot D) - (X_E \cdot E) - (X_F \cdot F) - (X_G \cdot G)] - H \cdot I$$

where X refers to net cultivated area for each crop in the rotation;
D is the average yield per crop. Different rates were allocated depending on the stage of rotation of each crop (Shah et al., 1987);
E refers to rate of seed retention;
F refers to milling losses;
G refers to the amount of crops used for animal feed;
H refers to wastage; and
I is the conversion factor used to convert crop production in kg into calories.

Demand for food was based on a per capita requirement of 2 340 cal/day and was adjusted according to the age distribution. The target of 2 340 cal/day/person was set by His Majesty, the King, as a target to be reached by 1992 (Environmental Resources Ltd., 1988). The caloric requirements of the adult consumption unit factor (ACU) (FAO, 1972) were scaled in accordance with the population's age distribution. Population estimates were available from the 1981 district population census data. Finally, the proportion of total calories from crops is assumed to be 90%, while 10% of food supplies are contributed by animal sources. Based on these assumptions, the model was run to determine overall food production (supply) for all 75 districts and the food requirements (demand) were calculated using minimum daily calories for the population in each district.

To arrive at estimates for the year 2000, it was assumed that the resource base of 1981 would not change and the only factor that influences the food calculations for 2000 is population growth. Population growth rates differed by district to reflect current migration rates, with the district average equalling 2.3%. While it is very simplistic to assume that resource variables do not change between 1981 and 2000, it is becoming evident that expansion of the cultivated area, crop intensification, and production inputs are extremely limited in Nepal. This implies that large yield increases are difficult to achieve (Ives and Messerli, 1989; Hrabovszky and Myan, 1987). Some authors have indicated that yields have decreased in many areas of Nepal over the past ten years (Environmental Resource Ltd, 1988; Asian Development Bank, 1982).

A serious shortcoming of the resource surplus/deficit model is that trade is not considered. This was done because virtually no information on the amount and type of food exchange is available, the transportation infrastructure does not exist, and more than 90% of the people in Nepal are occupied in subsistence farming. The choice of using current yield values for predicting future production can thus be justified.

Evaluating the Fodder Resources

The same method to determine food sufficiency was used for calculating animal feed sufficiency. However, the spreadsheet model included feed supplies from both agriculture and forestry.

The LRMP district livestock data were tabulated to include cattle, buffalo, sheep and goats. Pigs and chickens were excluded from the calculations because no reliable data for nutrient demands were available. The total digestible nutrient (TDN) demand was calculated using guidelines provided by FAO (1972) and animal statistics from the LRMP survey (LRMP, 1986).

To arrive at total feed demand for each district, the number of animals in each category was multiplied by the rate of TDN demand per type of animal. The supply of feed was determined by multiplying the areas of each land use class and rotation type times the annual feed yield rates. Adjustments were also made to account for fodder from trees on terrace risers and bunds, and from kitchen waste (LRMP, 1986). The total supply and demand balance was then calculated in the same manner as the food sufficiency calculations. To estimate feed demands for 2000, livestock growth rates were simply equated to one-half the population growth rate for each district, with the district average equalling 1.1%.

Evaluating the Fuelwood Resources

Fuelwood production was estimated using yield data for each LRMP forest type category included in the inventory. In addition, provisions were made to account for fuelwood supplies from shrubland, grassland, agriculture, and non-cultivated inclusions. To determine fuelwood supplies, LRMP yield data were multiplied by area data for each land use category. Fuelwood demand estimates were obtained for each district from the domestic energy model of the Water and Energy Secretariat. They range from 354 kg/person/year in the Terai to 677 kg/person/year in the High Mountains.

Once again, the surplus/deficit positions were calculated and each district was assigned a surplus, sufficiency or deficiency rating according to the results of these calculations. The 1981 figures are based on the actual data collected during the LRMP survey, while the figures for the year 2000 were calculated using the growth of population and livestock numbers as the only two changing variables.

Results

The combination of the spreadsheet model and the GIS capabilities allow the resource status for each district to be portrayed in a very dynamic and flexible way. GIS display maps were produced showing surplus, sufficiency and deficits for all three resources and all 75 districts for all years between 1981 and 2000. We calculated the resource status of Nepal for the year 2000, not to make actual predictions, but to simply test how the model responds to population and livestock growth. What became most apparent from the analysis was that, contrary to common belief, Nepal is not facing a fuelwood crisis, but animal feed and food deficits would be very common around the turn of the century. The food deficiencies are of particular concern. Many of the Terai districts, which were claimed to be the bread baskets of food supply for the rest of the country, appear to be food deficit areas as a result of very high population growth rates, due to high fertility rates and substantial migration from other areas.

GIS also made it possible to combine the resources to arrive at an overall assessment of resource poverty. Districts where classified into different poverty classes: all three resources in deficit, two out of three, and one out of three in deficit, sufficiency with no deficit or surplus, and various types of surpluses. Figure 1 represents the combined resource evaluation for Nepal for the year 2000. It is clear that resource sustainability is in question, and by the year 2000, the results of the model indicate that only seven out of 75 districts would have food surpluses, and only six districts would have surpluses in feed. On a national basis, the resource situation in Nepal in 2000 can be summarized as follows: a 27% deficit in food, a 54% deficit in feed, and a 6% surplus in fuelwood.

The projection maps given in Figure 1 can provide planners and decision makers with some idea of what would happen if the resource base remains unchanged from 1981 while population and livestock numbers grow. They can also be used to direct policy attention to those districts where resource deficits are likely to be most severe. The next step is to develop deficit elimination scenarios. GIS can play a key role in this process, since it facilitates the calculation and displaying of deficit elimination scenarios. If we assume current growth and consumption rates, the model can calculate what changes in key variables would be required to eliminate the deficits in each critical district. For example, the GIS model can determine when during the next 30 years each district will reach fuelwood deficits (Figure 2). To eliminate such deficits we can calculate by how much we would have to increase the tree biomass production or how much would we have to enlarge the area of tree planting. This 'what if' capability of the GIS based model has now advanced sufficiently that we can consider scenario evaluation on a real-time basis. The scenario model is intended to assist decision makers in determining the magnitude of the efforts needed to achieve resource sufficiency for individual or combined variables.

The sensitivity of the model was tested by determining how changes in key variables influenced the resource surplus/deficit calculations. At current growth rates, Nepal in the year 2000 would have an overall food deficit of 27%, a feed deficit of 54%, and a fuelwood surplus of 6%. In the case of fuelwood, the following variables were used to determine the overall response to the supply and demand calculation by a 10% change in population growth rates,

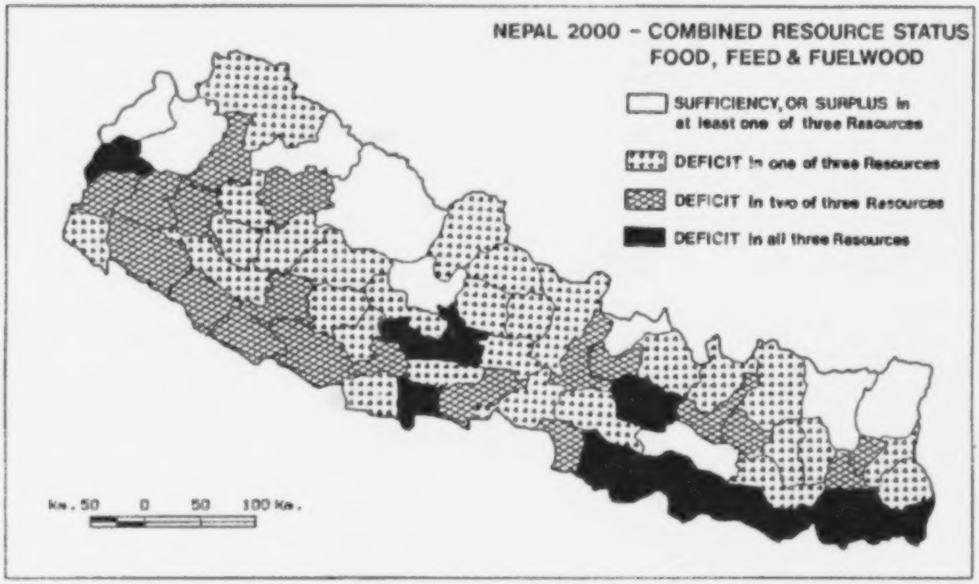
NEPAL 2000 - COMBINED RESOURCE STATUS
FOOD, FEED & FUELWOOD
SUFFICIENCY, OR SURPLUS in at least one of three Resources
DEFICIT in one of three Resources
DEFICIT in two of three Resources
DEFICIT in all three Resources
Km. 50 0 50 100 Km.

Figure 1. Combined resource evaluation of food, feed and fuelwood balance sheets for all districts in Nepal for 2000.

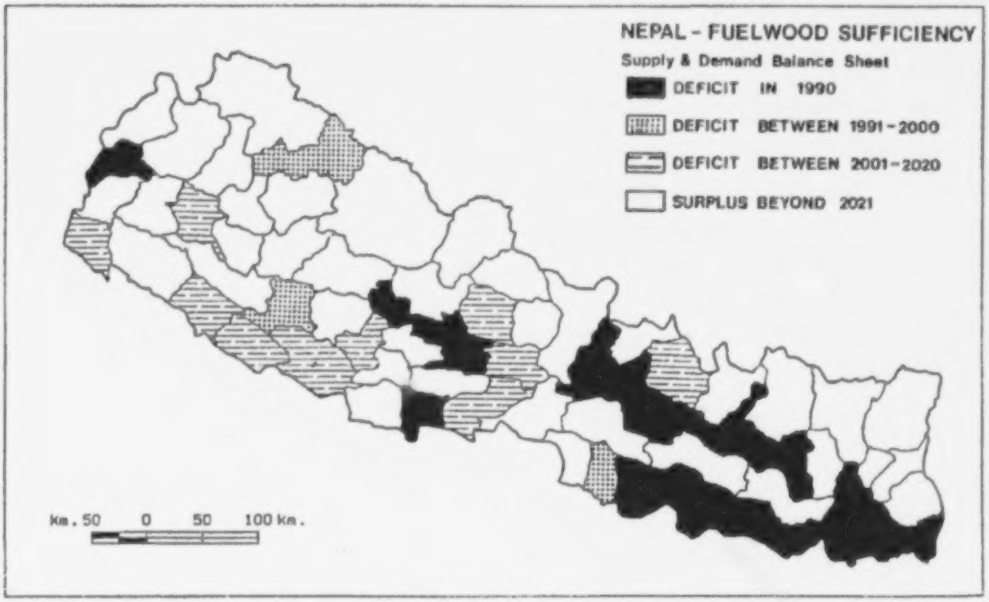
NEPAL - FUELWOOD SUFFICIENCY
Supply & Demand Balance Sheet
DEFICIT IN 1990
DEFICIT BETWEEN 1991-2000
DEFICIT BETWEEN 2001-2020
SURPLUS BEYOND 2021
Km. 50 0 50 100 km.

Figure 2. Time period in which districts are expected to reach fuelwood deficits under current population growth, current production & consumption rates.

biomass production, area planted in trees, and fuelwood demand.

Overall biomass production and changes in fuelwood demands were found to be most sensitive in altering the overall balance sheet calculations.

Conclusions

The following conclusions can be made from using the GIS based model:

1. The GIS model indicated that under current growth rates, animal feed is the most deficient resource in Nepal. The combined resource status for 2000 showed that only 9 of the 75 districts will have supply and demand balance sheets that are positive in more than one of the three resources (food, feed, or fuelwood). The animal feed and food situation is most critical, while the fuelwood status is expected to be the least problematic.
2. GIS allowed us to display the year when each district is expected to reach deficiencies in any one resource. Under current population growth rates, about 20% of all districts would be deficient in fuelwood in the year 2000.
3. The GIS based model enabled us to evaluate development scenarios and to identify key variables in a rapid and innovative manner. The model provided insight into the magnitude of the efforts needed to eliminate fuelwood deficits and with the sensitivity analysis, the key variables that drive the calculations could readily be identified. Linking a spreadsheet model to a GIS system provides a new dimension for understanding and evaluating resource sustainability at the national planning and policy level. The key to running such models is the availability of process or rate of change data. Unfortunately, such data are scarce and if available cover only short time cycles.

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Quantitative GIS Analysis of the Forest Resources in a Mountain Watershed in Nepal

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Abstract

The sustainability of the forest resources in Nepal has been questioned by many authors and the present study was initiated to:

1. document historic changes in forest cover;
2. determine relationships among soil fertility, site conditions and forest use in order to produce soil fertility maps; and,
3. make predictions as to the future supply, demand and sustainability of the forest resources.

A detailed GIS based watershed study was carried out in the Middle Mountains of Nepal and land use changes were quantified between 1972 and 1989. Contrary to general belief, the GIS evaluation provided no evidence that the forested area has changed significantly over the 17 year period. Significant relationships were found between site conditions, soil fertility, and forest use indices. GIS-based classification of aspect/elevation classes showed that north and south facing slopes above and below the 1200m elevation had significantly different soil fertility conditions, suggesting that topographically induced micro-climates are critical considerations for forest management. Based on these relationships, the GIS aspect/elevation classification capability enables us to predict and display the fertility status of individual and combined variables for the entire watershed. The intensity of forest utilization determined from interview data and forest use indices was positively related to soil deterioration. GIS facilitates the quantification of these processes and forms the basis for developing an improved management plan.

Introduction

The forests in Nepal are the major source of many vital products such as timber, fuel, animal fodder, agricultural compost, and medicine. A rapidly expanding population and increases in tourism are putting tremendous pressures on the forests (Ives and Messerli, 1989). Questions are raised relating to the sustainability of the forest, soil erosion and soil fertility maintenance. Little quantitative information is available concerning the changes in quantity and quality of the forest and the associated forest soil fertility.

In 1988, a three-year IDRC funded research project was initiated to investigate soil erosion, sedimentation and sustainability of soil fertility in relation to different land uses in the Jhikhu Khola watershed in the Middle Mountains of Nepal (Schreier et al., 1989). The aims of the project are to examine processes relating to soil erosion, sediment transport, soil fertility changes and land use changes in a quantitative way, using conventional and microcomputer based Geographic Information System (GIS) methods. As part of the watershed project, a study was carried out to investigate the dynamics of the forests in a 1270 ha test area.

The aims of the study are:

1. To characterize changes in land use, with a focus on the forest resource, from 1972 to 1989;
2. To investigate the relationships among forest use, soil type, soil fertility, site and forest parameters in the upper part of the Jhikhu Khola watershed in Central Nepal;
3. To develop a method to extrapolate from forest soil fertility measurements taken at specific points to unsampled locations in order to produce soil fertility maps; and,
4. To show how present supply and demand of forest products (fodder, fuelwood, litter) can be projected into the future under different management scenarios and societal demand level scenarios.

Methods

The forest and agricultural land use was mapped using 1:20 000 scale aerial photos taken in 1972 and 1989. All 1989 land use units were verified in the field and the boundaries were transferred into Terrasoft-GIS at the University of British Columbia (UBC) using an AP190 analytical plotter.

Detailed measurements relating to soil fertility, forest condition and forest utilization were taken at 136 randomly located sample points within the forest and grassland units of the study area. Figure 1 shows the location of the sample points within the study watershed. At each site, a three metre radius plot was sampled and the following data were recorded: tree and shrub species and dbh, dominant slope, aspect and elevation and various indices of use. Three composite surface soil samples and one composite litter sample were collected from each plot and the soils were classified by soil type. Foliar samples were collected from the dominant species in the plot.

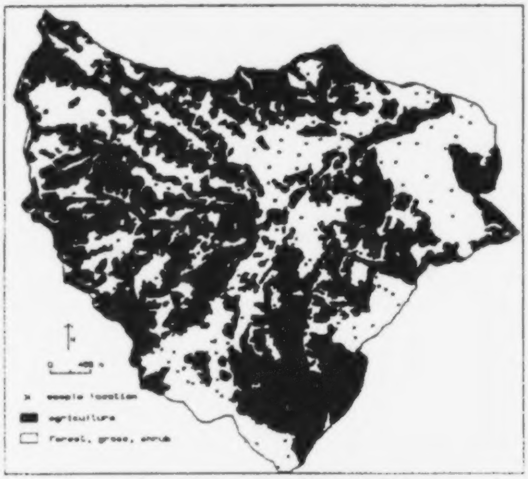

Figure 1. Location of Sample Points Within the Study Watershed

Finally, farm interviews were conducted to arrive at indices of forest utilization. Each house within the study area was marked on the aerial photos and the numbers of people and livestock were recorded. The house locations were digitized directly into Terrasoft using the AP190. Fifty structured household interviews were carried out to quantify the demand for forest products and to characterize the history, management and use of the forests.

All major soil nutrients were determined in the UBC soil laboratory. The litter and foliar samples were analyzed for nutrient content (calcium, magnesium, potassium, nitrogen, phosphorus, iron and aluminum). The level of forest use for each sample point was objectively ranked on the basis of the measured indices of use. Relationships among forest use, soil type, soil fertility, site and forest parameters were tested. A method of predicting soil fertility parameters based on measurements of forest use, site and forest parameters was developed.

The total areas in various land uses were determined from the digital data base for 1972 and 1989 and the changes in land use were determined by overlaying the 1972 and 1989 land use maps on GIS. This comparison provides information on the dynamics of recent changes among grass, forest and agricultural land use. The measurements taken at specific points in the study area were used to extrapolate to the rest of the forest area based on the information available for all forest areas, such as slope, aspect, elevation, species composition, soil type, indices of use, etc.. Slope, aspect and elevation were extracted from the digital terrain model which was produced using the 1:20 000 contour map of the study area. Single parameter fertility maps, such as a percent carbon map, were produced. The single soil parameter maps can be combined to produce composite fertility index maps such as a percent carbon and percent base saturation map. The resulting maps are useful indicators of forest sustainability indicating the overall nutrient status in the forest and the location of good and nutrient impoverished forest sites.

Results

Three aspects of forest sustainability were evaluated with GIS:

- Land use change;
- Forest soil fertility evaluation; and
- Relationships between soil fertility, site conditions and forest use.

Land Use Change

The changes of the following four land use categories were measured with GIS between 1972 and 1989: forest, grassland, irrigated agriculture and sloping terraces. Table 1 shows the overall land use change over the seventeen year period. The most striking feature of the land use evaluation is that there has not been a large amount of change in land use during the recent past in this area. Contrary to general speculation, there is no evidence that the forest area has decreased substantially. The amount of grassland has decreased by 10 % and the amount of sloping terrace land has increased by 9 %. Figure 2 illustrates the amount of change amongst the four land use categories. The most significant change has been from grassland to sloping terrace and to forest. A small amount of forest area has been converted to grassland and to sloping terrace. There has been very little change in the irrigated agricultural land.

Table 1. Land Use Changes in the Upper Jhikhu Khola Watershed

	Area (ha)			Percent		
Land Use	1972	1989	Change	1972	1989	Change
Grassland	399	279	-120	2	22	-10
Forest	397	378	-19	31	30	-1
Irrigated agriculture	82	106	+24	6	8	+2
Sloping terraces	389	505	+115	31	40	+9

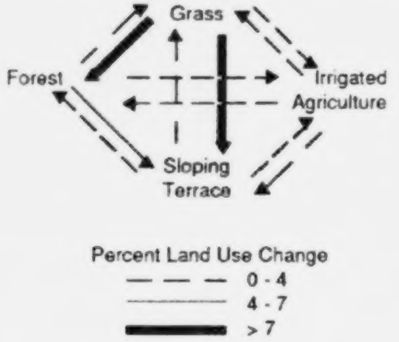

Figure 2. Changes Among Land Use Categories

Table 2. Mean Values for Soil Parameters by Forest Type

Parameter	Sal Dominated n=26	Mixed Hardwoods n=75	Pine Dominated n=15
pH	4.18	4.27	4.44
C (%)	0.47	0.65	0.72
N (%)	0.06	0.09	0.11
CEC (cmol/100g)	11.81	14.65	14.94
EB (cmol/100g)	2.31	2.61	3.60
BS (%)	20.73	19.35	24.81

Forest Soil Fertility Evaluation

The soil fertility analysis indicates that the forest soils of the study watershed are low in the following parameters: pH, percent carbon (C), percent nitrogen (N), available phosphorus (P), cation exchange capacity (CEC), exchangeable bases (EB) and percent base saturation (BS). The soil fertility status in relation to soil type and forest type can now be summarized and displayed in GIS; selective displays can be produced to determine inputs necessary for improvement of productivity. An example of the difference in soil fertility conditions between forests dominated by sal (*Shorea robusta*), pine (*Pinus roxburghii*) and mixed hardwoods is provided in Table 2. Sal forests had the lowest values for all listed soil parameters, pine had the highest values and mixed hardwoods were in the middle. The fact that sal and mixed hardwoods had lower soil fertility values might indicate that these stands are being more heavily utilized.

The GIS data base enables us not only to display the location of the different forest types and their associated soil fertility status but also to display selective combinations of deficient nutrients and the areas involved. This sets the basis for developing a forest improvement plan.

Relationships Between Soil Fertility, Site Conditions and Use

Significant relationships were obtained between various soil parameters and soil type, topography, species and degree of use. Two examples are provided to document these relationships and to illustrate how GIS can be used in improving forest management:

1. Aspect/elevation and its effect on soil conditions; and
2. Forest utilization and its effect on soil fertility.

1. Aspect/Elevation and Its Effect on Forest Soil Fertility

Given the large local relief in Nepal, there is a great variation in moisture and temperature within the watershed and quantification of aspect and elevation in GIS can be used to subdivide the watershed into distinct micro-climatic classes. North facing sites at high elevations above1200m are usually cool and moist, while south facing sites at low elevations below 1200m are usually hot and dry. All sites were classified into four different aspect/elevation type categories (above and below 1200m, dominantly north and dominantly south aspect).

Table 3. Mean Values and Differences Between Soil Parameters and Aspect/Elevation Classes

Parameter	S <1200 m n=33	S >1200 m n=11	N <1200 m n=25	N >1200 m n=48
Compaction	3.9	4.0	2.3	2.3
Exposed Soil(%)	39	24	8	8
C (%)	0.40	0.45	0.63	0.79
N (%)	0.05	0.07	0.09	0.12
CEC (cmol/100g)	12.50	13.80	13.03	16.07

Significant Differences Between Micro-Climatic Classes

	S, >1200 m	N,<1200 m	N, >1200 m
S, <1200 m	Expsoil	Comp Expsoil C N	Comp Expsoil C N CEC
S, >1200 m	Comp Expsoil N C	Comp Expsoil N C	
N, <1200 m			C N CEC

Mann-Whitney significant at $P<0.05$.

A number of soil variables were related to the aspect/elevation induced micro-climatic indicators and as shown in Table 3, north slopes have lower soil compaction (Comp) and percent exposed soil (Expsoil). North slopes and areas at higher elevations have higher percent carbon, nitrogen and cation exchange capacity, indicating that they are more fertile. Aspect has a greater influence than elevation, which suggests that moisture has more effect than temperature.

From Table 3, it is evident that all four micro-climatic site classes can be differentiated on the basis of essential soil nutrient conditions. These relationships can now be used to predict the nutrient status of all forests in the test area. The selective soil conditions can readily be classified and incorporated into a GIS forest management planning model which allows us to combine aspect/elevation classes with forest soil fertility status and forest type and to graphically display selective conditions at will. For example, percent carbon is significantly related to aspect and elevation, as shown in Table 2. As a result the watershed can be divided into four aspect- elevation classes and thus percent carbon can be portrayed in Figure 3 as a percent carbon map.

2. Forest Utilization and Its Effect on Land Use

The measured biophysical indicators relating to land use and the interview data on forest use were compared with the forest soil fertility status. Each plot was ranked from minimum use to maximum use for litter, fodder, fuelwood and grazing. These numbers were summed and the resulting sums divided into three classes of use, minimum, moderate and maximum. A number of variables were found to be significantly different between these three categories of use (Table 4). Compaction and percent exposed soil are lowest for the minimum use while percent carbon and nitrogen are lowest for the maximum use sites. The minimum use sites have the highest percent crown cover and the lowest percent pine.

This means that we can deduce forest use intensity from the fertility status, or predict the fertility status from land use data obtained from interviews. In both cases, GIS allows us to readily represent the conditions in a very dynamic manner.

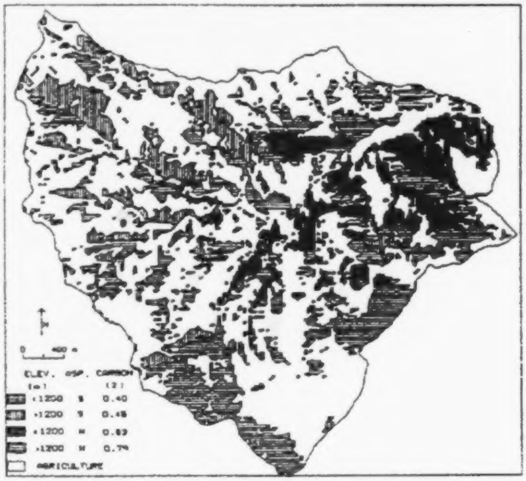

Figure 3: Percent Carbon Map

Table 4. Mean Values and Differences Between Soil and Site Parameters and Use Class

Parameter	Minimum Use, n=42	Moderate Use, n=53	Maximum Use, n=41
Compaction	2.3	3.1	3.4
Exposed Soil (%)	10	20	25
C (%)	0.68	0.58	0.55
N (%)	0.10	0.08	0.08
% Crown Cover	61	45	37
% Pine Cover	6	11	33

Significant differences Between Land Use Classes and Soil Conditions

	Moderate Use	Maximum Use
Minimum Use	Comp Expsoil C N Cover Pine	Comp Expsoil C N Cover Pine
Moderate Use		Comp Cover Pine

Mann-Whitney significant at $P<0.05$

Future Work

Having determined rates of land use change and obtained human and animal population growth rates from interview data, it is now possible to develop a quantitative model for projecting the supply and demand of forest products (fodder, fuelwood, litter) into the future. Knowing the relationships between land use, bio- physical indicators and soil fertility status, it is possible to arrive at biomass production rates under different input scenarios. The supply of forest products will be estimated using measurements taken in this study, as well as information from interviews and literature sources. Having a combined socio- economic and bio-physical data base allows us to develop a comprehensive and dynamic forest management model that is capable of establishing the following management scenarios:

1. What is the production potential for fuelwood, fodder and litter under current demand?
2. When does the demand exceed the supply under current conditions?
3. What is needed in terms of human and animal population reduction to reach a balanced budget between supply and demand?
4. What is needed to improve soil fertility and what effect would it have on productivity? and
5. How many trees need to be planted to satisfy future fuelwood demands?

Conclusions

GIS is facilitating the measurements of processes by allowing us to quantify and display land use change and to portray relationships between land use, site conditions and soil nutrients in a spatial manner. The results of our study so far indicate that:

1. There has been little land use change in the Nepal test area and anticipated losses of forest land mentioned by the World Bank (1979) are unsubstantiated for this area;
2. The soil fertility conditions in the watershed are generally poor but there are substantial differences between soil types and forest types;
3. A number of good relationships were found between land use, site and soil variables. These allow us to predict soil and land use conditions from site variables and bio-physical indices;
4. Combinations of aspect/elevation classes, as determined by GIS, were found to have unique nutrient conditions, thus suggesting that micro-climatic conditions have a significant influence on site conditions; and,
5. Land use intensity was found to be responsible for soil nutrient deterioration in the different forests. With GIS, it is readily possible to quantify and display combined use, site and soil conditions, thus laying the foundation for developing a dynamic GIS based forest management plan for the area.

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GIS for Assessing Habitat and Estimating Population of Red Pandas, Langtang National Park, Nepal

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Abstract

A microcomputer-based Geographic Information System (GIS) database was developed for Langtang National Park, Nepal. This database was used to study the habitat, population, and risk of local extinction for red pandas (*Ailurus fulgens*). GIS capabilities most relevant to park managers included area measurements, easy updating of digital data, overlay preparation, distance measurements, terrain modeling, scale change, attribute selection, density analysis, buffering and corridor analysis, and the ability to facilitate 'what if' planning. The results of the study suggest a population of 24 pandas isolated into four or five groups by physical barriers such as rivers and high ridges. Unless these patches of core habitat are protected from cattle grazing and other human disturbances, red pandas are destined for extinction in Langtang National Park.

Introduction

Park managers and natural resource planners working with the design and implementation of national parks require information on the physical attributes of a park (soil, slope, aspect, climate), the socioeconomic aspects of land use in or near the park (grazing customs, firewood collection patterns, location of neighboring villages), and the needs and lifecycles of the plant and animal communities found in the park (habitat, population, migration). Two of the most pressing problems park managers in developing countries face are a lack of reliable information, and insufficient financing and under-staffing for processing what information is available. To overcome these problems, planners need tools for analyzing and updating spatial information quickly and efficiently.

Geographic information systems (GIS) utilize computer-based techniques for encoding, analyzing and displaying multiple data layers. Microcomputer-based GIS can serve the needs of local communities as well as those of national planning offices, and can be adapted to different societal values, beliefs, and ways of doing things.

Geographic information systems have been used to model the habitat of a wide rage of species (Tomlin et al., 1987; Young et al., 1987; Hodgson et al., 1988; Agee et al., 1989). These studies typically map the occurrence of key environmental variables and develop overlays that suggest areas of potential habitat. Data layers often include elevation, soils, vegetation, topography, distance to watering areas, distance to roads and other human activities. Aspect and slope are obtained from elevation data using terrain modeling capabilities. GIS buffer facilities have also been used in these applications. Some studies have used radio-tracing devices to help model habitat requirements (Scepan et al., 1987; Young et al., 1987). As habitat requirements are better understood, the models can be adjusted and new maps easily produced to aid both management and research.

This project sought to demonstrate the usefulness of microcomputer-based GIS technology for assessing the habitat of red pandas in Langtang National Park, Nepal, using this information to estimate red panda population and modeling the risk of local extinction.

Background

Langtang National Park

Langtang National Park encompasses 1719 km² of the central Himalayan region of Nepal (85°15' to 86°0' E and 28°0' to 28°20' N). The northern and eastern boundaries of the park follow the Nepal-China (Tibet) border, the Bhote Kosi-Trisuli River forms the western border; and the southern border lies about 32.2 km north of the Kathmandu Valley. Elevation in the park ranges from 1 000 to 7 245 m and plant communities extend from upper tropical forests to regions of alpine scrub and perennial ice. Climatic and vegetative zones have been described and classified in detail (DUHE, 1977; Yonzon, 1989). Thirty-two mammal species are known to occur in the park (DUHE, 1977). Although many rare mammals such as wild dog (*Cuon alpinus*), wolf (*Canis lupus*), red panda (*Ailurus fulgens*), clouded leopard (*Neofelis nebulosa*), snow leopard (*Panthera uncia*), and musk deer (*Moschus chrysogaster*) occur in the park, the low density of larger mammals is an indication of the extent of intrusions by man.

About 30 000 people use Langtang National Park's resources for fuelwood, for livestock grazing and for other allied activities. Protected areas have thus become part of the larger lived-in landscape by both traditional and modern conventions (Hamilton, 1988). The Langtang Valley produces only enough food to provide 25% of the annual per capita food requirements (DUHE, 1977). Because of growing human population and an increasing deficit in food production, people rely on livestock to provide a cash income. One study, DUHE (1977), estimated that between 6 861 to13 147 GLU (Grazing Livestock Unit) are dependent on park fodder resources. This means that approximately 686 100 to 1 314 700 tons of green fodder are collected in the park every year.

The Red Panda

The red panda, the sole species in the monotypic family *Ailuridae*, originally inhabited the temperate forests from Nepal through Sikkim (India), Bhutan, northern Burma and part of southern China (Pocock, 1941). Mukherjee (1982) reported the presence of red pandas in Kangchendzonga National Park, Sikkim, and other authors have claimed that red pandas are widespread in the north-east Himalayas (Rodgers and Panwar, 1988). MacClintock (1988), however, reported that red pandas are extinct in Sikkim. Nothing is known about the panda in Bhutan except for its presence in Jigme Dorje Wildlife Sanctuary. Bhutan's new wildlife legislation, which is under review, may provide some fresh insights. Although pandas have been reported in Arunachal Pradesh (Mukherjee, 1982, Rodgers and Panwar, 1988), and perhaps in Namdhapa National Park, their correct status is not known. In Burma, a survey conducted in 1959-60 suggests the occurrence of pandas in the Chaukan Pass area (Milton and Estes, 1963). No confirmed sightings or museum specimens have been recorded from Arunachal Pradesh or northern Burma. In China, pandas have been reported in south-eastern Tibet (Feng et al., 1981), west Yunan and Sichuan (Expedition of rare animal species, 1977), and in Shaanxi (Wu and Hu, 1980). In Nepal and India, the red panda is a protected species (Upreti, 1980; Saharaia, 1982), but their numbers are dwindling as intense human pressure affects their habitat. Red pandas may be near extinction in Nepal with sparse populations found in Langtang and Lambagar (central Nepal). Information from eastern Nepal is primarily anecdotal.

Through natural selection in a limited and isolated environment, the red panda has adapted to a narrow range of environmental conditions. Although a carnivore by taxonomic placement and anatomical characteristics, its food habits indicate that solitary pandas have a fairly narrow, herbivorous diet (Yonzon, 1989). The life history of pandas is characterized by seasonal breeding, and a small litter size with high survivorship of young. These patterns of adaptiveness suggest that pandas have evolved to survive in undisturbed communities. In terms of evolution, habitat specialists are the result of successful adaptations to climax communities, an adaptation that makes them highly vulnerable to disturbance (Pianka, 1970; Terborgh and Winter, 1980). Cub mortality, for example, was as much as 83 to 86 percent in Langtang due to high-altitude cattle grazing and the associated disturbances (Yonzon and Hunter, 1989). This evidence suggests that red pandas are rare and highly vulnerable. If they are not to face extinction, more must be learned about the problems they face and about practical solutions for overcoming these problems.

Although described in the early 1800s by Hardwicke (1827) and Hodgson (1847), until very recently, (Johnson et al., 1988; Yonzon and Hunter, 1989; Yonzon, 1989) the only studies of red pandas have been with captive populations (Roberts and Gittleman, 1984; Glatson, 1982). A World Wildlife Fund study in Langtang National Park from 1985 to 1987 was the first field research directed toward the long-term conservation of pandas (Yonzon, 1989). The overall objective of the study was to develop techniques for assessing red panda distribution and to provide information on its life history and habitat.

After unsuccessfully attempting to capture pandas for 720 trap-days from food and scent-stations, an innovative capture technique was designed to noose pandas in the tree-tops. Following capture, radio collars were installed to monitor movements and activities. It took 1 110 man-hours of searching over 2 years to generate 10 observations on free-ranging pandas by a team of investigators. Six pandas were radio-collared. Half of the monitored adult population was killed by natural predators or by man (Yonzon, 1989). Cub mortality was associated with cattle grazing and human disturbances; cattle occupied the entire panda habitat during the summer and the monsoon season. Thus, pandas are facing a precarious situation even in the protected areas.

Habitat

Nine different habitat types were recognized (Yonzon and Hunter, 1989). These included fir (*Abies spectabilis*)-jhapra, rhododendron (*Rhododendron campanulatum*), broad-leaved species-*raate* (probably *Thamnocalamus aristatus*), birch (*Betula utilis*), and alpine scrub. Two other habitats, rhododendron-juniper (*Juniper recurva*) and fir-birch, were recognized but always occurred in patches of less than 0.25 ha. Pandas were not found in open scrub or pasture lands. Of the 1522 radio-locations, 92 percent occurred in the fir-jhapra forest. In addition, indices of electivity (Ivlev, 1961) with values ranging from -1 to +1, suggested fir-jhapra as the preferred habitat type.

The average elevation at which red pandas were found in all seasons was 3233 m ± 218 m with a range of 2800 to 3900 m. Altitude range was seasonally different ($X^2 = 230.06$, $p < 0.00005$). Pandas were found at their lowest average elevations in December (2991 m) and highest in September (3397 m), suggesting that pandas are largely limited to an altitude range of 406 m. This is an extremely narrow range in comparison with other mammals in such terrain (Green, 1985; Wilson, 1981).

The project monitored movements of six radio-collared pandas on 1522 occasions and collected 3478 panda pellets (Yonzon, 1989). All evidence suggested that red pandas made extensive use north-facing slopes covered with fir-jhapra forests. Evidence of pandas was not found on south-facing slopes. South facing slopes have a longer sunlight period, and do not support fir-jhapra vegetation.

GIS Analytic Framework

The habitat model developed in this project sought to answer several basic questions about red pandas. These questions include:

1. where are the core areas of red panda habitat within the park?
2. what is the estimated red panda population? and
3. which core areas are at risk based on surrounding landuse practices?

A GIS provided the necessary tools to analyze and display the information required to answer these questions. The basic hardware used by the project was a Hewlett-Packard Vectra RS/20 with a 100 megabyte harddisk. The software used was pc ARC/INFO. For determining aspect, the topographic database was ported to a mainframe-based ARC/INFO system. Three factors were used to model red panda habitat and thereby extrapolate fieldwork observations to the rest of the park: forest cover, elevation, and aspect.

Factor 1: Land Use-Land Cover Map

The first task was to identify all fir-jhapra forests in the park. Land utilization maps (1:50 000) prepared by the Land Resources Mapping Project (LRMP, 1984) were used. The GIS joined nine separate map sheets to create a land cover map for Langtang National Park. The LRMP maps identified forest cover by major species for areas as small as 0.25 km². This project labeled areas of coniferous forest dominated by fir or juniper, and areas of mixed forest with fir dominant and oak (*quercus*) absent, as favorable red panda habitat. These areas are collectively identified as fir-jhapra forest in Figure 1.

Factor 2: Elevation Map

Contour information at 500 m intervals was obtained from 1:125 000 district topographic maps (Nepal Topographical Survey, 1986). Three separate map sheets were jointed to create an elevation map for the park. Because contours at 2800 and 3900 m were not available, 3000 and 4000 m contours were used to bound favorable red panda habitat. Areas between these contours are shown in Figure 2.

Factor 3: Aspect Map

The third factor was aspect. Red pandas prefer west, north or northeast facing slopes (azimuths of 180-359 degrees and 0-45 degrees). Using the triangular irregular network (TIN) component of the GIS, elevation contours and spot heights of critical points were used to define a topographic surface. Aspect was calculated at 0.25 km² resolution for all areas within the park. The aspect map was simplified into two aspect categories, favorable or unfavorable, as displayed in Figure 3.

Overlay Analysis of Three Factors: Core Habitat Map

The three factor maps were developed from map sheets drawn at different scales and projections. The GIS standardized these maps to a common scale and projection. Standardized maps were then combined in a process known as overlay analysis. This analysis produced a map showing areas in the park with forest cover, elevation, and aspect favorable to red pandas. The distribution and total area of favored red panda habitat can be seen on this map, in Figure 4.

Land Use Surrounding Core Habitats

Buffers were developed to determine landuse practices in a 500 m band surrounding the core habitats. The core habitat map was used to generate a series of 500 m wide buffers around the core areas. These rings were then used like a cookie cutter to clip out the equivalent areas from the land use map. The resulting map, Figure 5, shows land use within each of the buffer rings.

Jhapra is one of the five species of ringal bamboo found in the park. Jhapre is the local name, (Type 29, C. Stapleton, pers. comm., probabley *Himalayacalamus falconeri*) is the most accurate term available until the taxonomic controversy of the Nepali ringal bamboo is resolved.

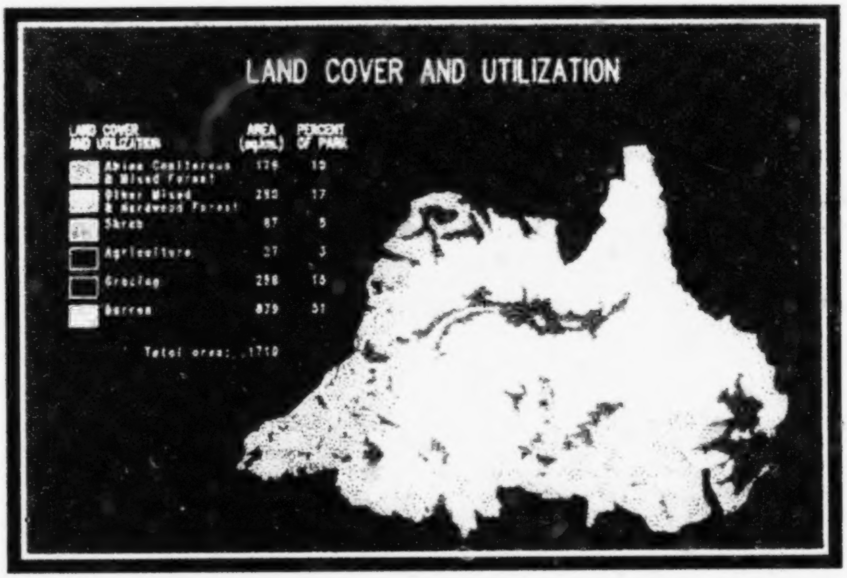
LAND COVER AND UTILIZATION
LAND COVER AND UTILIZATION
AREA (sq.km.)
PERCENT OF PARK
Abies Coniferous & Mixed Forest 176 10
Other Mixed & Hardwood Forest 293 17
Shrub 87 5
Agriculture 37 3
Grazing 258 15
Barren 879 51
Total area: 1710

Figure 1

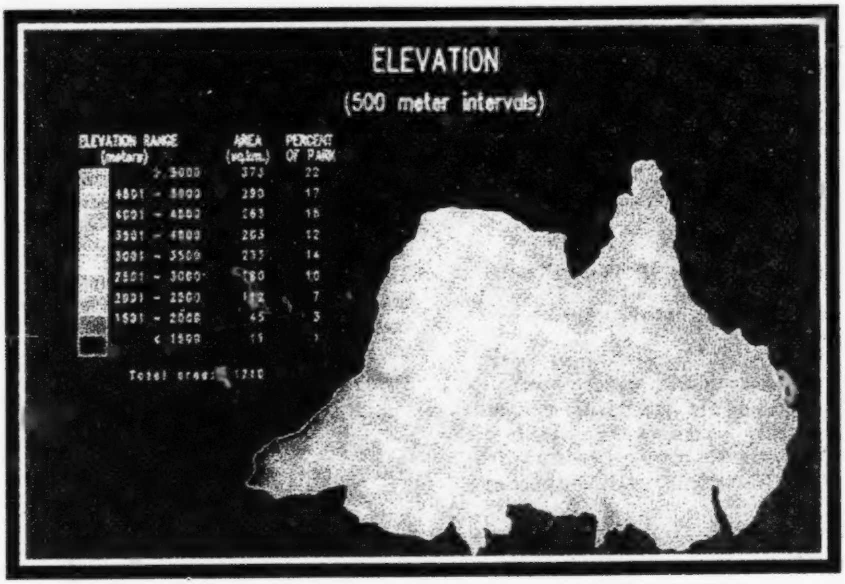
ELEVATION
(500 meter intervals)
ELEVATION RANGE (meters)
AREA (sq.km.)
PERCENT OF PARK
> 5000 373 22
4501 - 5000 293 17
4001 - 4500 263 15
3501 - 4000 203 12
3001 - 3500 235 14
2501 - 3000 180 10
2001 - 2500 112 7
1501 - 2000 45 3
< 1500 15 1
Total area: 1710

Figure 2

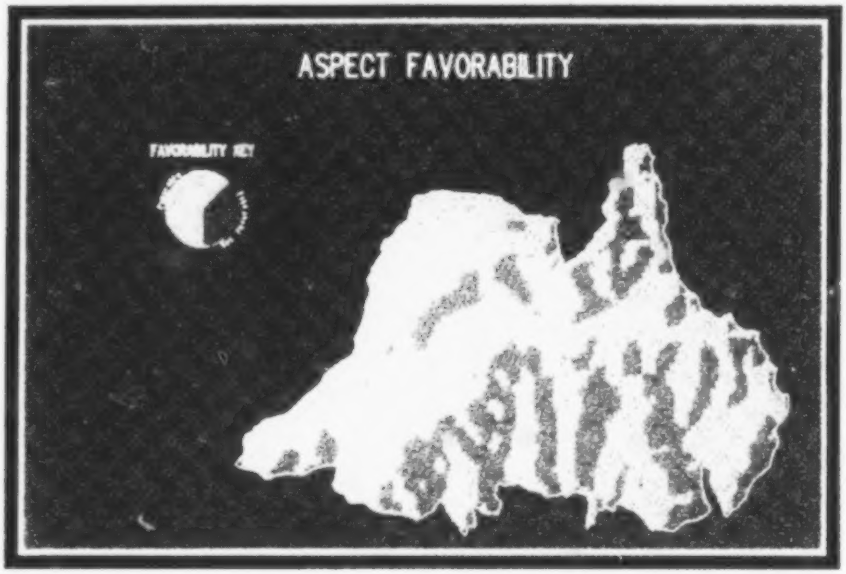
ASPECT FAVORABILITY
FAVORABILITY KEY

Figure 3

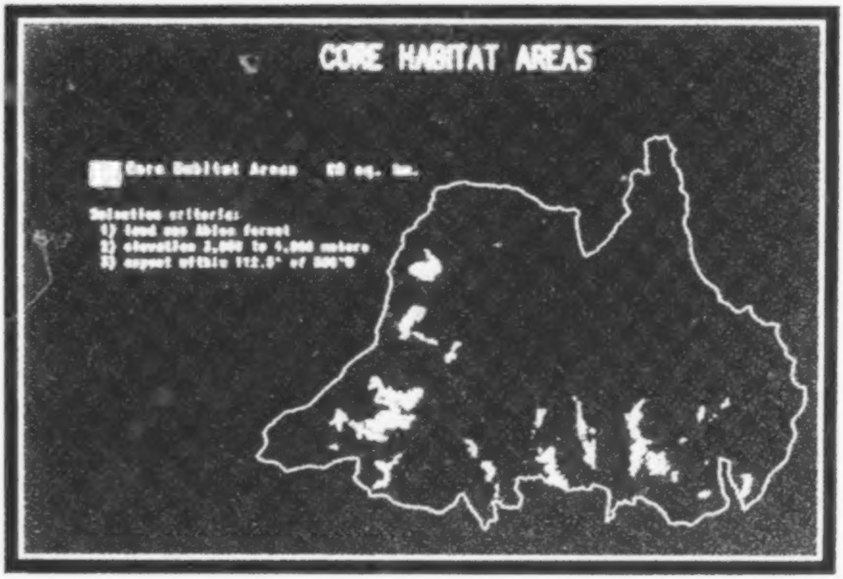
CORE HABITAT AREAS
Core Habitat Areas [illegible] sq. km.
Selection criteria:
1) land use Abies forest
2) elevation [illegible] to 4,000 meters
3) aspect within 112.5° of [illegible]

Figure 4

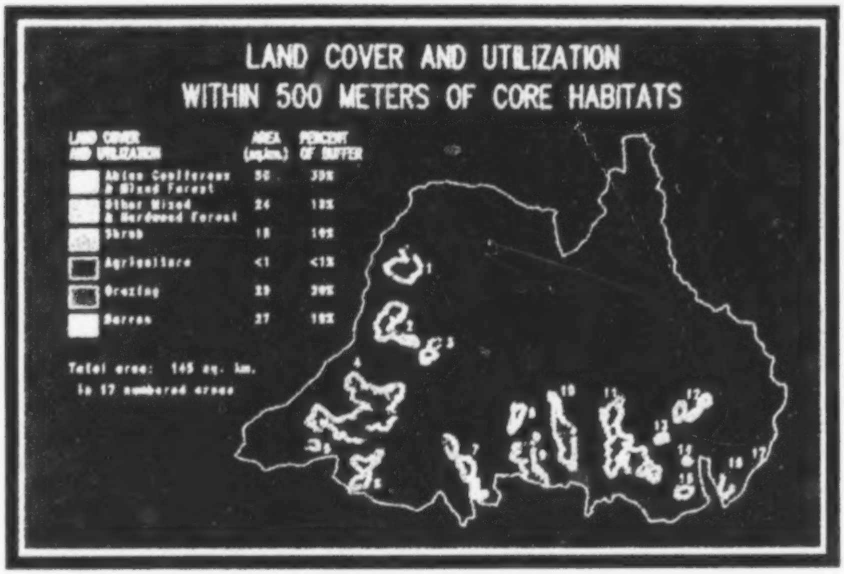
LAND COVER AND UTILIZATION
WITHIN 500 METERS OF CORE HABITATS
LAND COVER AND UTILIZATION
AREA (sq.km.)
PERCENT OF BUFFER
Abies Coniferous & Mixed Forest 50 34%
Other Mixed & Hardwood Forest 24 17%
Shrub 15 10%
Agriculture <1 <1%
Grazing 29 20%
Barren 27 19%
Total area: 145 sq. km.
in 17 numbered areas

Figure 5

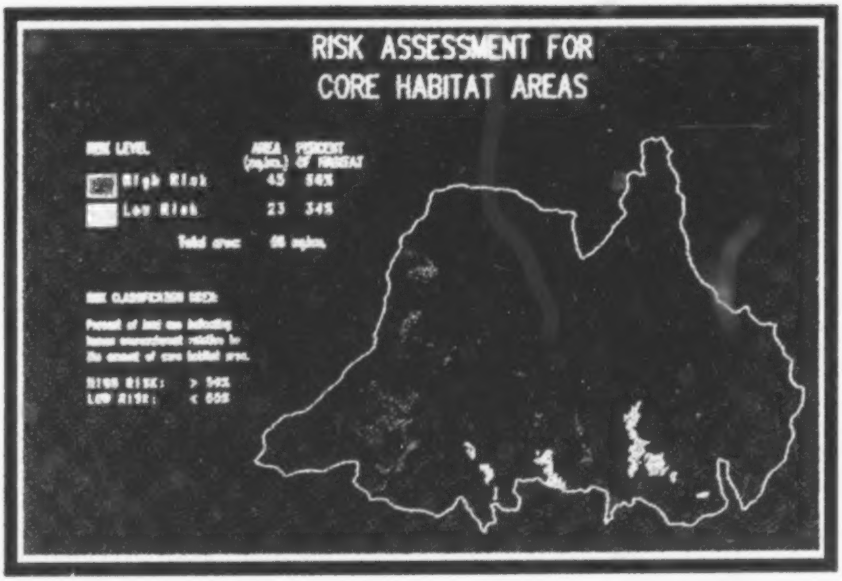
RISK ASSESSMENT FOR
CORE HABITAT AREAS
RISK LEVEL
AREA (sq.km.)
PERCENT OF HABITAT
High Risk 45 66%
Low Risk 23 34%
Total area: 68 sq.km.
RISK CLASSIFICATION INDEX:
Percent of land use indicating human encroachment relative to the amount of core habitat area.
HIGH RISK: > 50%
LOW RISK: < 50%

Figure 6

Core Areas at Risk

Three land use types were assumed to indicate human activities which could place core habitat areas at risk. Agriculture and grazing were assumed to pose risks since their extension into the core habitat would directly diminish the amount of favorable habitat available. Shrub areas were assumed to be a product of extensive firewood collection and therefore posed a risk because firewood collection within the core areas would degrade the habitat. These landuse types were combined into one category indicating human utilization.

The landuse buffer map was divided into nineteen non-contiguous areas for risk analysis. If the amount of human-utilized land in the surrounding buffer exceeded the amount of habitat in the core, then the area was classified as being as high risk due to human pressure. Otherwise, the areas were classified as low risk; both high and low risk areas are shown in Figure 6.

Results

1. Population Estimate

Assuming pandas range between 3000 and 4000 m, and occupy fir-jhapra forest on west, north and northeast slopes, the estimated total area of suitable habitat in Langtang National Park is 68 km^2. Based on an ecological density of one panda per 2.9 km^2 (Yonzon, 1989:59), the study estimated that the population of red pandas in Langtang National Park is 24 pandas. Isolation between concen-trations of suitable habitat is such that the Langtang pandas are probably isolated into 4 different populations.

2. Risk

Sixty-six percent (45 km^2) of the core habitat was found to be at high risk due to human pressure. Smaller core areas are all at risk. Several of the larger core areas, including the field study site, are also at high risk, primarily because of grazing and firewood collection. Agriculture did not contribute significantly to the risk factor as it is only present in one buffer area.

Discussion

Conserving the red panda's habitat will ensure that the habitat requirements of many other wildlife species are also protected. The red panda may thus serve as a flagship species. If the red pandas are lost, or severely reduced in numbers, a major perturbation in the system is indicated. Maintaining the viability of the natural systems means maintaining viable populations of all such species (Soule and Simberloff, 1986). Nature preserves with large undisturbed areas are considered ideal because they ensure long-term maintenance of bio-diversity. But such ideal conditions do not exist in many parts of the central Himalayas (Nepal) and thus are not realistic and feasible. Because the existence of strict protected areas is becoming increasingly difficult as human populations grow, in many developing countries, the conservation of flagship species such as the red panda will be a more efficient means of safeguarding bio-diversity than the 'minimum area approach' (Soule, 1987) Successful management depends on reconciling the conflicting needs of nature protection and the local people in a new form of conservation.

If park managers and farmers are to communicate, the park manager must start the process by understanding the farmers' landuse practices. Park managers need to know how private and public lands are used and must see landuse practices in their spatial context. Knowing which practices are found where and how location affects these practices is as vital as knowing what the practices are and who owns the land.

A GIS provides a number of capabilities that enhance the ability of park managers to understand local landuse practices and which promote the development and implementation of conservation strategies. The GIS capabilities which were most relevant to this project include area size measurement, easy updating of digital data, overlay, distance measurement, terrain modeling, scale change, attribute selection, density analysis, buffering and corridor analysis, and the ability to facilitate 'what if' planning. Maps created by a GIS can also serve as tools for resolving conflicts between park managers and local residents (Fox, 1989). Creating a GIS database requires a significant initial investment of time and effort to automate resource information. The more uses to which such a data base can be put the more cost effective it will be. The ultimate justification for developing a GIS, however, depends on whether the system provides capabilities that were not previously available or completes existing tasks more efficiently.

Conclusions

This project illustrates how a GIS can be used for modeling wildlife habitat and assessing the effect of outside activities on this habitat. The results of this study indicate that red pandas in Langtang National Park are threatened. The estimated population of 24 individuals in the park is so low that their survival is in question. Furthermore, these 24 pandas are isolated into four or five populations by physical barriers such as rivers and high ridges.

The core habitat of 68 km^2 is fragmented into more than 17 patches. All patches are under pressure from man-related activities such as cattle grazing and firewood collecting. Sixty-six percent (45 km^2) of the core habitat was considered under high risk. Unless these patches of core habitat are protected from cattle grazing and other human disturbances, red pandas are destined for extinction in Langtang National Park.

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Concurrent Session 11

Environmental Issues - Integrated Use

Implementing GIS into Alberta's Integrated Resource Planning Program

Development of a GIS Implementation Plan for the Yukon Department of Renewable Resources

The role of GIS in Integrated Resource Management for First Nations Initiatives in Alberta

GIS-based Simulation of Moose Habitat Carrying Capacity in Northwestern Ontario

Integrated National Land Resource Coverage: New Zealand Experiences

GIS'91

Symposium

Vancouver
British
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February 1991

Implementing GIS into Alberta's Integrated Resource Planning Program

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Abstract

The Province of Alberta's Integrated Resource Planning Program is used to provide direction for the management of public land and resources. Over the past 15 years since the Program's inception, change has occurred in personnel, processes, and deliverable products. The recent introduction of GIS technology into the Resource Planning Branch has the potential for helping professional planners undertake their activities in significantly different ways. A host of new capabilities and different methodologies may evolve from this marriage.

In order to successfully implement GIS into our organization, a GIS implementation strategy has been prepared and is currently being undertaken. Our plan identifies primary goals, objectives, and specific means by which this technology transfer will occur. Of crucial importance has been the support and commitment of the Branch's management and planners. The use of a structured implementation strategy has the greatest potential for ensuring a successful incorporation of GIS into the integrated resource planning process. This paper presents details on the strategy, methods, and issues that must be addressed for a successful implementation. A review of preliminary results with respect to resource planning applications is also provided.

Introduction

Public land and resources provide considerable benefits to Albertans. Given the variety of these resources, the diversity of benefits, such as jobs, enjoyment, clean air and water, to be achieved from these resources and the myriad of values held by a pluralistic society like Alberta's, wise resource management is a crucial but difficult task. Integrated resource planning, (IRP), is one decision-making process used by the Government of Alberta to pursue wise management of public land and resources now and in the future.

Since Alberta obtained control of public land and resources from the federal government over 60 years ago, a large amount of resource information has been compiled for the many resource sectors found in the province. Many departments, boards and agencies have evolved, most of which have a narrow legislative mandate to manage a particular resource sector. These jurisdictions are frequently spread across all three levels of government and each resource sector often has a unique public constituency made up of residents, leaseholders, industry and interest groups that act as advocates for certain management outcomes. Accordingly, when integrated resource planning is undertaken there is a large amount of information, for a large number of resource sectors, being brought to the table by a large number of people.

The IRP program is a typical situation that could benefit greatly from the use of GIS. Better decisions could be made faster using more information and considering a larger number of alternatives. The Resource Planning Branch, (RPB), has been monitoring the development of GIS technology since the early 1980s and has participated in the application of GIS through pilot projects in the Department of Forestry, Lands and Wildlife. This past fiscal year has seen the justification of and acquisition of a personal computer based GIS system for use in the IRP process.

With acquisition of the system, the IRP program is 'on the learning curve'. This paper focuses on the implementation strategy that is being undertaken. Initially, implementation is directed internally at the Resource Planning Branch, while in the future, all interdepartmental clients and participants will be targeted. GIS must be implemented in a way that is consistent with, and enhances the principles of integrated resource planning. One of the key issues is the need to secure training and ongoing systems support. These services, along with a commitment from program managers, a suitable data stream for individual planning areas, and a recognition of documented pitfalls and implications should ensure a successful technology transfer to the IRP program.

Background

Integrated Resource Planning

The federal government transferred control of natural resources to the province of Alberta in 1930. Today, the majority of Alberta's natural resources, including 62 percent of the land base and virtually all fisheries, wildlife and mineral resources, are publicly owned. Alberta's public land is an important base for petroleum, natural gas, minerals and forest products, and much of the tourism and ranching industries. The headwaters for the major river systems of the three prairie provinces are located on public land in Alberta. Habitat for most of the province's wildlife is also found on these lands and they are a source of many of the recreation activities of Albertans.

During the 1950s and 1960s, increasing pressures on the public land base for oil, gas and coal development and for more recreation and wilderness areas, resulted in the need for additional resource legislation. During the 1970s, the need for better communication and coordination among involved agencies was recognized and administrative structures and procedures were established to this end. Subsequently, the development of the integrated resource management approach was initiated. The government responded in 1975 by forming the Eastern Slopes Interdepartmental Committee, which reported to Cabinet and was responsible for making recommendations on an integrated resource planning approach. **A Policy for Resource Management of the Eastern Slopes** (1977), identified integrated resource planning as the key to effective management of the natural resources found on the Eastern Slopes of the Rocky Mountains. This Policy has since set the framework for the integrated resource planning system for all provincial public land and resources in Alberta.

Integrated resource plans are currently prepared by interagency planning teams that are coordinated by a resource planner from the R PB. Twenty-one plans have been completed in the province to date, and 16 plans are currently being worked on.

GIS Activities Within Forestry, Lands and Wildlife

GIS activities within the Department of Forestry, Lands and Wildlife have a rich history. Most of the GIS applications have been und ertaken directly by the Resource Information Branch, (RIB), of the Land Information Services Division, (LISD). RIB has provided access to GIS technology and consulting services to several divisions throughout the Department. These include the Public Lands, the Alberta Forest Service, and the Fish and Wildlife Divisions.

Most of the activities undertaken have involved pilot projects and prototype development. These include a wide range of applications, most of which were identified during a Departmental user needs analysis conducted during 1986. GIS technology was first acquired in 1983 with the purchase of the ARC/INFO software. Since that time, several other software offerings have been acquired and used for a variety of different applications. GIS software currently used in the Department include Intergraph MGE, ARC/INFO, SPANS, PAMAP, and Terrasoft. Most GIS software in the department operates on DOS-based microcomputers, with the exception of ARC/INFO and Intergraph minicomputer (VAX) and workstation (UNIX) platforms.

The current focus of GIS applications in the department has been on integrating the technology in accordance with existing agency mandates and operational guidelines. LISD has developed significant expertise in applying GIS tech-nology to land management problems and is currently developing several production systems. Many of these will support the IRP process.

Principles of Integrated Resource Planning

Seven principles are integral to, and provide the foundation for, integrated resource planning. They apply to the IRP program and it s public involvement requirements. The principles are :

1. Integrated resource planning is **procedurally fair.** Everyone affected by a decision has the opportunity to participate. Through teamwork, everyone interested has an opportunity to participate in the resource management decision making processes. Those responsible for the management of public land and resources have an opportunity to participate as

committee members, who review plans or as planning team members, help develop the plans. Opportunities for participation through the public involvement program are also available.

2. Integrated resource planning **ensures open communication**. There are many government agencies, industries, groups with various resource interests and concerns, and many individuals who require public land and resources in order to meet their needs. Therefore, decisions about the management of resources must be made with a high degree of coordination.

3. Integrated resource planning **encourages shared decision making** where decisions are reached by **consensus**. Through shared decision making, all participants have an opportunity to provide information, understand government objectives and influence decisions. Consultation takes place before action is taken. Consensus is viewed as a general accord in effecting a purpose. The final decision rests with the government.

4. Integrated resource planning is **rational**. It relies on the best available information from many sources and works through identification of needs and objectives. It also looks at alternatives to define the best way to achieve the agreed upon objectives and it defines the actions required to implement the decisions. The decision making process ensures that resource management issues are resolved through a series of three rational steps: collecting information; choosing appropriate action to meet objectives; and imple-menting decisions.

5. Integrated resource planning is **comprehensive**. It recognizes that the management of one resource influences how other resources are used and allocated. Therefore, an interdisciplinary approach is taken in the management of public land and resources. This includes economic, social and environmental data. All natural resources are addressed, all interests are considered and all levels of decision makers participate.

6. Integrated resource planning is **dynamic and flexible**. It can respond to changing needs and circumstances, both in the development stages and in the future, when revisions or amendments are needed. It can be tailored to suit issues and circumstances of resource management decision making. Integrated resource planning is a continuous, often repetitive process of decision making.

7. Integrated resource planning is **coordinated by an impartial body**. Varied interests among parties involved with natural resource interests, such as government agencies, industry, groups and individuals, are a reality. Coordination of decision making must therefore create a level playing field and cannot be accomplished if the coordinating body has a vested interest in the outcome of the decisions.

Integrated resource planning strives to abide by the above principles in all activities, including GIS applications.

If the application of GIS is to be successful, we cannot compromise the above principles. Clearly, GIS will support the principle of a rational approach to decision making while allowing an even more comprehensive approach. It will encourage the sharing of decision making as it allows participants to understand and work through analytical processes that agencies use to make decisions. F lexibility can also be enhanced by offering opportunities to use more types of information in a more creative manner. As well, GIS holds the promise for facilitating public involvement and it will allow more alternatives to be explored.

Fair procedures must be maintained when using GIS technology or it will not contribute to integrated resource planning. It would be intolerable to let an individual or a group, that has the GIS expertise to access the data of other stakeholders drive the decision making process. All stakeholders must continue to be involved in the outcome of decisions arrived at through integrated resource planning. Without consensual decision making, which is the cornerstone of IRP, the process will fail.

Hardware and Software

It became obvious through the involvement in GIS pilot project activities during the 1980s that GIS technology could be an appropriate tool to facilitate the IRP process. Accordingly, in April 1990, the RPB acquired the SPatial ANalysis System (SPANS) from Tydac Technologies Inc. SPANS was selected because of its strong data integration, advanced analytical modelling capabilities and compatibility with data sources. These capabilities are in line with the analysis and overlay requirements of integrated resource planning.

SPANS Version 4.3 was installed on a 386-based microcomputer employing the IBM DOS operating system (Version 4.0). However, due to recent enhancements to SPANS under the IBM OS/2 operating environment, plans are underway to upgrade to Version 5.0 during the next fiscal year. Version 5.0 of SPANS provides significant enhancements to the analysis and modelling functions as well as providing a state of the art windowing user interface. Testing has indicated that the user interface enhancements will greatly shorten the learning curve for RPB planners and lead to an increased use of the system. Fiscal justification and planning is currently underway.

The Implementation Plan

A well planned and structured approach to implementing GIS technology is necessary to achieve an optimum return on investment. It is important to remember that GIS is a long term investment. Implementing of GIS technology is no different than investing in any automated data processing technology and requires the appropriate business planning.

The starting point for the development a realistic implementation strategy for the RPB included a thorough review of the experiences of other GIS users. A focus of the GIS literature available stresses implementation issues and strategies. It was decided that this valuable information would make a suitable starting point for the development of an implementation plan. The implementation plan was developed in accordance with other Departmental agencies, particularly RIB, to make use of their experience. The implementation plan is divided into five sections:

1. Goals;
2. Objectives;
3. Activities;
4. Implications; and
5. Critical Requirements.

A review of each follows.

Goals

To effectively utilize GIS technology, initially by focusing on SPANS in the preparation of integrated resource plans, the analysis of resource policies and alternatives, and supporting the public involvement program.

Objectives

1. To ensure that each planning officer understands the capabilities of, and is proficient in, the use of the SPANS software by April 1, 1992.

2. To initiate an integrated resource plan within the SPANS environment by April 1, 1992.

3. To make use of SPANS software in at least one public meeting during 1992-93.

4. To ensure that proper organizational adjustments are made to accommodate the successful integration of GIS capabilities into appropriate daily business activities.

Data compilation represents the single most expensive part of the GIS implementation process. This involves the digitizing and converting of existing analog data to a digital format consistent with the specific requirements of the SPANS software. This process requires experienced personnel. This service will be provided by the RIB. RIB has long provided RPB with data (maps and reports) in support of the integrated resource planning program. Their experience in GIS applications will certainly help the RPB minimize the cost and time required to put the required databases in place.

Activities

1. Pilot and Demonstration Projects

Pilot projects are a valuable means of assessing progress and identifying problems early, before significant resources have potentially been wasted. Accordingly, the first step will be the initiation, in July 1990, and the completion, in January 1991, of three pilot projects. The focus of these projects is on Branch staff. This will allow the planning staff to work through some realistic application scenarios while learning the requirements and capabilities of the GIS. It is important to realize that the pilot projects are a crucial step in the implementation process. They will allow the organization to adjust itself to the substantial commitment that is required for successful implementation. The progress of the GIS implementation will be judged by the first products that are realized. Early impressions tend to be long remembered.

2. Major Demonstration Project

Based on the activities and experiences of the pilot projects, one major demonstration project should be initiated by January 1, 1991, for one of the interdepartmental clients of the RPB. The results of the pilot projects will help to identify areas or applications that are better suited for the technology.

3. Training

Part of a successful implementation of GIS requires that adequate training be provided to RPB personnel. A major pitfall in many GIS implementations is the focus on training one staff member as the GIS specialist. Training will be provided to as many planning officers as possible within the realistic constraints of the pilot projects. However, the successful development of in-house expertise will require that at least some staff be permanently assigned to the GIS facility and be given the opportunity to become experts with the system. Assigning GIS activities to staff who already have full schedules, while not providing adequate hands on learning time, will result in failure. GIS has a steep learning curve and will require commitment from the planning officers and management. It cannot be treated as an 'add on' job requirement!

Creating an awareness and educating staff across the Branch will ensure the acceptance of the technology at all levels of the organization. In accordance with these training requirements, staff will be provided with GIS training beyond the specific software training offered by the vendor. GIS education will, in general, prove very beneficial in the long term application of the technology. The GIS course offered by the Department of Geography at the University of Alberta, entitled 'Introduction to Geographic Information Systems', provides a comprehensive curriculum of topics related to GIS focusing on application of the technology.

4. Management Training Course

In support of the education requirements, a general GIS overview course will be provided to RPB management. This will result in a bet ter understanding of the potential of the technology and may have long standing effects with respect to commitment of manpower and finances. The training course will define fundamental concepts and relate them back to the specific situation of the RPB.

5. Professional Participation

Part of the education process should occur through participation in professional conferences, seminars and informal networks related to GIS activities. A host of GIS related conferences and symposiums exist which can offer significant advantages. These conferences offer a vast amount of knowledge with respect to other agencies' activities and experiences, but can also provide valuable market profiles, aiding in the acceptance and justification of the investment in GIS.

6. Computer Hardware and Software Acquisition and Maintenance

Provisions will be made to allow for future maintenance and upgrading of the Branch's hardware and software options. Many of the new capabilities are ideally suited for RPB applications. Management should be aware of these requirements and plan for upgrading in the coming fiscal years.

7. Commitment for Support from the Resource Information Branch

The largest expenditure in implementing a GIS is in the creation of the database. Because data compilation is a time consuming process, often requiring very specialized skills and knowledge, it is best undertaken by an experienced party. The literature on GIS confirms that an average of 70% to 80% of the total expenditure for any project will involve the task of data compilation. As identified earlier, the RIB has previously provided this service to the RPB as well as other department agencies. It will be advantageous and consistent with existing procedures to have RIB continue to provide this service.

As the GIS technology comes on-line, it is vitally important that maintenance and ongoing support be supplied. Support is normally required in the areas of software maintenance, applications development, database design, and data compilation.

8. Assess Users Needs and Technical Issues

A vital part of the implementation process is the identification of user needs and related technical issues. This is commonly referred to as a user needs analysis. The initiation of the pilot projects will provide the needs infor-mation related to technical requirements and applicability. RPB will also use the user needs study undertaken by the Department in 1983 to identify relevant products and data requirements.

Implications

1. Learning Curve

It takes time to learn how to apply GIS technology. This means that approximately one to two years are required for staff to become comfortably and functionally operational with the software. Of course, this is fully dependent on the amount of time spent by individuals and the commitment by the organization. As previously identified, having planners learn GIS in addition to their other duties will only result in a flatter and longer learning curve. Figure 1 presents a graph reflecting software proficiency versus the number of years spent on it. This is referred to as the 'learning curve'. The actual point at which the curve steepens will depend on a variety of factors including commitment by the organization and the individuals involved.

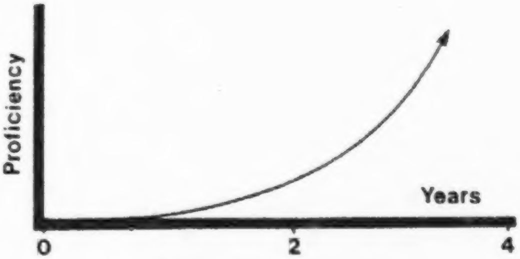

Figure 1. GIS Learning Curve

2. Productivity and Benefits

Even with a well defined implementation strategy, GIS will not provide immediate benefits. Recent studies indicate that conventional data processing business analyses do not completely identify all the potential benefits that automated geographic information access can provide. It is important to understand that the services and quality of work should also be rated along with quantifiable products. Intangible benefits constitute a large amount of the short and long term benefits of moving to GIS technology. Primary benefits include :

- increased reliability of information;
- reduced risk;
- enhanced capabilities to integrate information;
- greater analysis and output capabilities;
- improved cooperation between users;
- sharing of data between users;
- job satisfaction;
- improved marketing and public image capabilities; and
- reduced turn-around time.

However, it is important to realize that benefits and increased productivity are not achieved overnight. Most agencies have realized that a loss in productivity occurs over the short term while the GIS technology is being implem-ented and learned. This is primarily due to the learning curve and the time-consuming data compilation activity. Depending on the implementation process, increased productivity is normally reached between the second and fourth year of implementation. Figure 2 illustrates the typical situation.

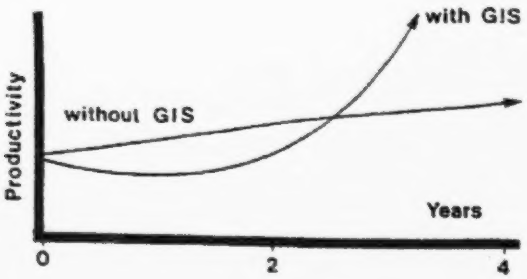

Figure 2. Effects of GIS Introduction on Productivity

3. Funding and Costs

The initial discussion of costs attributed to implementing GIS technology is usually constrained to the hardware and software costs. In fact, this is normally only 20% to 30% of the entire implementation cost. Undoubtedly the most expensive part of the implementation and maintenance process is the data compilation, commonly 70 to 80%. Accordingly, issues such as data accuracy, qual ity, and database design are very important. Any remaining costs accrue from training, contracting, and equipment main-tenance. These figures vary depending on the particular situation.

4. Staffing

Staffing and training will become major issues during the implementation of the technology. Both are critical to the success of the GIS implementation. New positions may be required, and new definitions of existing positions will evolve. Responsibilities must be defined for system management and maintenance, both hardware and software, database administration, applications development, data compilation, and data output. Several of these responsibilities have been addressed previously in this paper. Management should be aware that GIS skills are highly desirable in the marketplace and many users will want to acquire them. As well, the job market for individuals with those skills is dynamic. GIS skills and experience is currently a highly sought-after and valuable commodity. It may be necessary to re-write job descriptions and raise salaries once GIS skills have been developed in order to keep the more qualified individuals.

It is also important to note that consultants and contractors can provide valuable assistance during the implementation and start up phase. Staff working with an experienced GIS consultant can learn successful approaches and techniques directly instead of by trial by error. In particular, consultants are best used during the product assessment, user needs analysis, and data compilation activities. However, it is critical that when a consultant or contractor is to be used, that staff be actively involved so they can learn from the consultant's expertise.

Critical Requirements

The following factors are critical to the successful implementation of GIS technology within the RPB.

1. Recognition of the implications by management staff;
2. Organizational commitment to the technology so that all planning officers are provided with adequate time for learning the technology; and
3. A long term strategy to maintain a data stream and other support services.

Results and Conclusion

As identified in the implementation plan, three pilot projects are currently underway. The purpose of the pilots is to become familiar with problems and issues concerning data acquisition, structuring and analysis, software and hardware, and other needs. They involve all RPB planners and technical support staff. Data compilation and application development support has been provided by RIB. A brief review of each pilot projects follows.

1. Protected Areas Atlas

A compilation of protected and natural areas for a small area in Alberta which has digital data available. A variety of data layers have been compiled, including base map features such as hydrography, access, elevation, wildlife key areas, forest inventory and peatland inventory. Over 5 000 quarter sections of public land are covered by this pilot.

2. Visual Impact Assessment of the Bow - Canmore Corridor

This project is being done in conjunction with private industry and Alberta Tourism. Data layers include forest inventory, elevation , access, hydrography, zoning, mining, environmentally sensitive areas and proposed development.

3.Range Assessment in the Eastern Irrigation District

This pilot involves assessing the current range situation for the Bassano lease area of the Eastern Irrigation District. Data layers include base map features hydrography, access, survey fabric, elevation, irrigation canals and ditches, wetland areas and soil descriptions.

The pilot projects are allowing the Resource Planning Branch to learn about GIS while evaluating the technology in various situations of overlay approaches with a large number of stakeholders. The pilots are not related to any decision making in the study areas, but are simply demonstrations of the technology.

When the GIS system was acquired, it was expected that the steep learning curve would be a concern. However, presented in the proper manner, GIS can be fun as well as challenging for the professional planner or resource manager. The critical issue is that it is rarely given highest priority initially. Professionals can be cautious, skeptical, confused and sometimes intimidated at first . Accordingly, other activities are often considered more urgent, especially when goals are not well articulated. It is management's task to ensure that time is available to learn the required skills, and that hands on time for the GIS remains a priority. The issue will quickly change to limiting professionals time on the system once the critical learning point is reached. GIS can be addictive.

An obvious issue that has arisen is the different learning requirements of RPB staff. As expected, selected individuals have more in terest and aptitude than others. However, it is interesting to see the wide range between aptitude and skill on one hand and interest on the other, among personnel. Overall, the interest level is very high but currently only a few have the computer skills with the hardware, operating system (DOS), and the GIS software. Unfortunately, the current state of most GIS software requires competency in not only the GIS software but also the operating system. System and file management is not an issue that should be neglected during the implementation process. GIS is data intensive and requires organized data management skills.

The implementation of the pilot projects has indicated that more training is required. In particular, a general overview of microcomputers is necessary to bring staff to the required competency level. A second training session for the GIS software may also be required now that the pilot projects are underway. It is hoped that the move to the OS/2 version of SPANS will provide a friendlier interface for the planners. It is expected that this will greatly enhance the learning process. However, it does not negate the requirement for consistent hands on time.

Another expected issue is data. Alberta is working towards providing a number of inventories of digital resource based information s uitable for GIS type applications. Unfortunately, this is currently a goal and not a reality. Initiatives such as the Land Related Information System, the Integrated Resource Inventories, the Alberta Vegetation Inventory hold great promise for the future of GIS applic-ations. The issue of sharing data must also be addressed, especially as digital data becomes more readily available. The IRP process requires cooperation between a number of agencies and data must be shared for effective decision making. It is expected that GIS technology, in combination with the IRP process, will provide a stronger foundation for improved data sharing and coordination in the future.

GIS must adhere to and support, and where possible, improve the principles of integrated resource planning described above. None of these principles can be compromised or the IRP system will fail; it cannot be replaced by a technical tool like GIS. The application must not compromise fair procedures that recognize the mandates of all IRP participants. Communication and shared decision making will be enhanced as agencies develop IRPs around GIS, as opposed to traditional manual data management techniques. The rationality and comprehensiveness will be supported as new, previously unavailable data is acquired. It will facilitate dynamic and flexible approaches to decision making.

The three pilot projects initiated in July 1990 support the application of GIS technology to the integrated resource planning process and associated responsibilities of the Resource Planning Branch. The focus of these pilots is on planning team coordinators at this time. It is expected the next step will be to broaden the base of participation to include all participants in integrated resource planning decision making. The Resource Planning Branch remains excited about the promise that GIS holds for integrated resource planning in allowing comprehensive, rational resource management decisions arrived at in a timely manner.

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Development of a GIS Implementation Plan for the Yukon Department of Renewable Resources

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Abstract

Crippen Consultants, a Division of H.A. Simons Ltd., has recently completed the development of a six-year GIS implementation plan for a Resources and Lands Information System (RLIS) for the Yukon Department of Renewable Resources. The RLIS will be a computer-based system comprising two key technologies: a Geographic Information System (GIS) and a Remote Sensing Image Analysis System (IAS).

To ensure the successful implementation of the RLIS, the planning team followed a rigorous planning methodology. The work of this first phase, system specification, was divided into four steps: requirements definition; alternatives analysis and recommendation; development of the implementation plan; and preparation of a management presentation. The remaining implementation work has been divided into three phases: system design, system acquisition, and system commissioning.

Overview

This paper describes the process followed by the Yukon Department of Renewable Resources (DRR) and Crippen Consultants to develop a six-year plan to implement a Resources and Lands Information System (RLIS).

History

In March of 1986, the Yukon DRR requested that an Information Systems Plan be developed as part of an effort to improve the planning, control, development and management of the Department's programmes. One of the plan's recommendations was to automate DRR's geographically referenced databases. A proposed RLIS would combine Geographic Information System (GIS) and Image Analysis System (IAS) technology to allow DRR to utilize spatial data in a more efficient manner.

In October of 1989, DRR issued an RFP to develop an executable implementation plan to establish the RLIS. Crippen Consultants, a division of H.A. Simons Ltd., was contracted in December of 1990 to produce this plan.

Yukon Department of Renewable Resources

The Yukon DRR is charged with the responsibility of ensuring that " ... the environment and renewable resources of the Yukon are managed and used on a sustainable basis." The Department's objectives must balance a diverse range of requirements including:

- conservation of renewable resources and the protection of genetic diversity;
- support of development of the renewable resource economy in a sustainable manner;
- integration with other economic sectors to provide optimum benefit to all Yukoners;
- ensuring that environmental management reflects the rights and responsibilities of the Yukon's aboriginal peoples; and
- ensuring the involvement of all Yukoners in the development and review of programmes, policies, legislation and regulations.

A more complete discussion of these issues can be found in **Yukon Conservation Strategy: Our Common Future** (Government of Yukon, 1989).

DRR has five Branches and ten Sections situated at three locations in Whitehorse, and Field Services staff throughout the Yukon. Approximately thirty of the Department's staff are potential users of the RLIS.

The GIS Implementation Process

Figure 1 shows the four-phase GIS implementation process that was used as a starting point for this project. This process is based upon systems development methodologies that have evolved over the past twenty years. While most consultants will follow some version of this process, the phasing and steps are usually customized to meet the specific needs of each organization.

The reason for using this process is to avoid the problems that typically occur during implementation:

- the functional and system requirements are improperly or incompletely defined;
- the cost estimates are incorrect;
- the implementation timeline is overly optimistic; and
- the system cannot grow to meet the future needs of the organization.

By following a step-by-step process, the risk of encountering these pitfalls can be significantly reduced. For this project, the scope of the work was to complete phase I; the system specification.

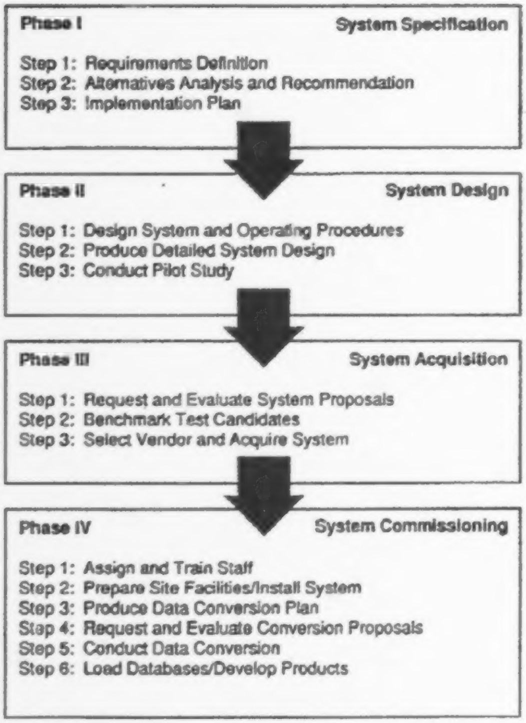
Phase I
System Specification
Step 1: Requirements Definition
Step 2: Alternatives Analysis and Recommendation
Step 3: Implementation Plan
Phase II
System Design
Step 1: Design System and Operating Procedures
Step 2: Produce Detailed System Design
Step 3: Conduct Pilot Study
Phase III
System Acquisition
Step 1: Request and Evaluate System Proposals
Step 2: Benchmark Test Candidates
Step 3: Select Vendor and Acquire System
Phase IV
System Commissioning
Step 1: Assign and Train Staff
Step 2: Prepare Site Facilities/Install System
Step 3: Produce Data Conversion Plan
Step 4: Request and Evaluate Conversion Proposals
Step 5: Conduct Data Conversion
Step 6: Load Databases/Develop Products

Figure 1: Four Phase GIS Implementation Process

Project Team

The project team included GIS implementation consultants provided by Crippen, an RLIS Steering Committee, and a Project Manager from the Government of Yukon's Systems and Computing Services (S&CS) department. The Committee was comprised of twelve DRR staff members, and provided user input to the whole process. All review meetings were run with the Committee; all project reports were reviewed by the Committee. The S&CS Project Manager ensured that the process met in-house standards, and assisted the consultants with the MIS aspects of the projects.

Step 1: Requirements Definition

The first step in the planning process was to produce a document which clearly defined the user requirements. This step was divided into three tasks: development of a user questionnaire, data gathering, and synthesis of the data into a requirements document.

User Questionnaire

A User Requirements Questionnaire was developed to gather information about the following topics:

- Department goals and objectives;
- Organization and structure;
- User applications;
- Data processing;
- MIS issues;
- Finance; and
- Technology.

A draft version of the document was produced by Crippen and reviewed by the Steering Committee for final approval. The complete questionnaire, including instructions, was thirty-five pages long.

The questionnaire used charts, tables and data sheets, with fields customized to DRR's applications and organizational structure. The document used both 'closed' and 'open' probes to balance the need for exact answers with the need to allow the users to express their requirements as freely as possible. A closed probe might ask specific questions about the scale, storage medium, symbology or security management of a particular map. An open probe might ask users to envisage how their current methods of manipulating spatial data would change once the RLIS was in place.

The information solicited by the document was of three broad types: background information, specific information, and physical documents such as maps, reports, data entry forms. Since some data could be gathered from senior managers within the Department, not every section of the questionnaire was answered by all staff members.

GIS Workshop and Data Gathering

The process of gathering requirements information was started with a one-day workshop in Whitehorse for all staff members who would answer the questionnaire. The purpose of the workshop was to introduce GIS concepts, and to explain the data gathering process. The 'Introduction to GIS' portion of the workshop was important since it was the first introduction for some of the staff to GIS concepts. The explanation of the data gathering process was also important since it allowed the users to review the questionnaire and to ask questions.

The data gathering task covered a four-week period. During the first three weeks, DRR staff answered the questionnaire and collected sample reports, maps and tables. During the fourth week, a Crippen consultant interviewed DRR staff and collected the sample documents. In addition to DRR personnel, staff members of organizations that DRR shared spatial data with were also interviewed.

At the completion of the data gathering task, the combined paper load would have easily filled three drawers of a filing cabinet.

Data Synthesis

Once the data was gathered, the information was analyzed and synthesized into a User Requirements document. This process always provides a major challenge since the plethora of responses must be distilled down to a common description of the user needs. A draft User Requirements document was produced, reviewed by DRR, and then updated for final acceptance. The document closely followed the questionnaire structure described above. Excerpts and comments from the GIS User Requirements document are provided below:

Goals and Objectives: The purpose of this section is to ensure that the consultant has a clear understanding of the organization. The goals and objectives were documented for DRR, and for its five individual branches.

Department Structure and Skill Sets: This section described DRR's organizational and physical infrastructure. Figure 2 provides an organizational chart for DRR. A major activity in developing this section was to estimate the number and location of possible users, and to evaluate the GIS and computer skill levels of these individuals. This information was used to estimate potential workload and user access requirements, and to develop strategies for introducing the technology, including training requirements.

MIS Issues: This section documented existing computer infrastructure and management practices. Issues such as the computing environment, backup and recovery methods, data security, and workstation ergonomics were addressed here.

Map Series and Spatial Databases: This section was the result of significant effort on the part of DRR and Crippen staff: it organized the large number of spatial data sets into a consistent inventory that described all of the spatial and spatial-related data maintained by DRR. In total, forty-nine (49) map series and spatial databases were identified and documented. For each map series, a database record was produced containing descriptive information such as a list of features, graphic data characteristics, attribute data characteristics, current uses, current users, data volume and security.

Synthesis of Requirements: This last section organized the map series listed in Table 1 into a more manageable set

Map Series/Spatial Database	MAPID	Map or Database Type
Outfitter Areas	M001	Base Information
Game Management Areas	M002	Base Information
Conservation Officer Districts	M003	Base Information
Ecoregions	M004	Base Information
Registered Trapping Concessions	M005	Base Information
Yukon First Nation Traditional Areas	M006	Base Information
Roads and Trails	M007	Base Information
Wildlife Key Habitat Database	M008	Wildlife Habitat
Wildlife Surveys	M009	Wildlife Population
Sheep Horn Curl Data	M010	Wildlife Population
Sheep Lumpy Jaw	M011	Wildlife Population
Hunting Licences/Seal Receipts	M012	Wildlife Harvest
Nonresident Hunter Harvest Database	M013	Wildlife Harvest
Resident Hunter Harvest Database	M014	Wildlife Harvest
Yukon Biological Submission Forms	M015	Wildlife Harvest
Fur Harvest Management Database	M016	Wildlife Harvest
Indian Harvest Survey	M017	Wildlife Harvest
Wildlife Relocation Surveys	M018	Wildlife Relocation
East Kluane Biophysical Inventory	M019	Biophysical Surveys
Kusawa Lake Ecological Land Classification	M020	Biophysical Surveys
MacMillan Pass Ecological Land Survey	M021	Biophysical Surveys
Southern Lakes Ecological Land Survey	M022	Biophysical Surveys
Stewart River/Atlin Area Aquatics	M023	Biophysical Surveys
Carmacks Forest Inventory	M024	Biophysical Surveys
Vegetation Inventory Field Database	M025	Biophysical Surveys
Vegetation Inventory Maps	M026	Biophysical Surveys
Dempster Highway Surficial Inventory	M027	Biophysical Surveys
Special Habitat Protection Maps	M028	Resource Inventory
Special Planning Project Maps	M029	Resource Inventory
Dempster Highway Corridor Study	M030	Resource Inventory
Watson-Wheaton Resource Inventory Study	M031	Resource Inventory
Protected Areas Inventory	M032	Resource Inventory
Resource Transportation Access Program Database	M033	Land Application Review
Land Use Permit Database	M034	Land Application Review
Agriculture/Grazing Soil Reviews	M035	Land Application Review
Agriculture Application Database	M036	Land Application Review
Commercial Wilderness Operators	M037	Land Application Review
Wood Cutting Permit Database	M038	Land Application Review
Land Application Review Database	M039	Land Application Review
Wood Cutting Maps	M040	Land Application Review
Natural Features Inventory	M041	Parks and Recreation
Recreation Features Inventory	M042	Parks and Recreation
Canadian Heritage Rivers	M043	Parks and Recreation
Potential Recreation Sites	M044	Parks and Recreation
Occurrences	M045	Miscellaneous
Violations	M046	Miscellaneous
Yukon Herbarium Database	M047	Miscellaneous
Wildlife Specimen Collection	M048	Miscellaneous
Stocked Lakes	M049	Miscellaneous

Table 1 - List of Map Series and Spatial Databases

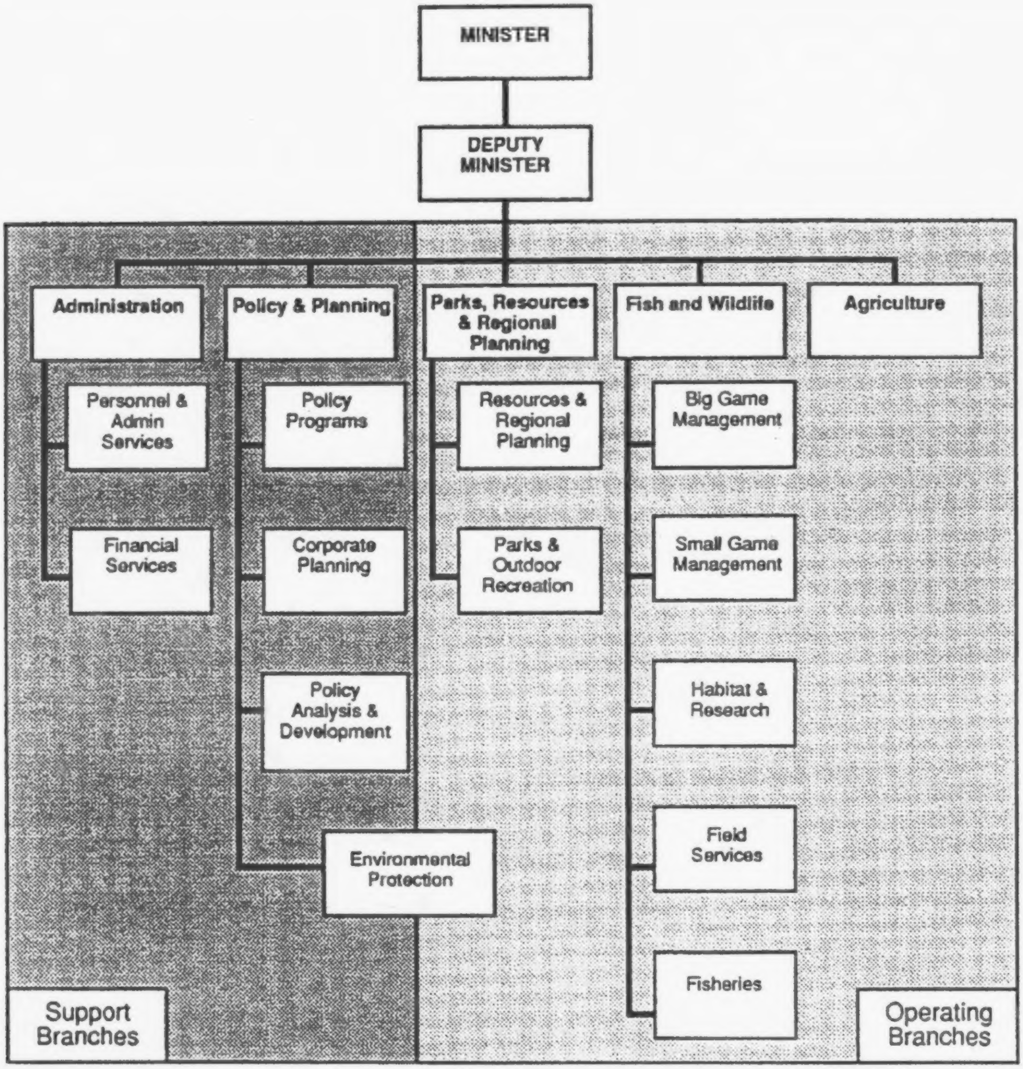
MINISTER
DEPUTY MINISTER
Administration
Policy & Planning
Parks, Resources & Regional Planning
Fish and Wildlife
Agriculture
Personnel & Admin Services
Financial Services
Policy Programs
Corporate Planning
Policy Analysis & Development
Environmental Protection
Resources & Regional Planning
Parks & Outdoor Recreation
Big Game Management
Small Game Management
Habitat & Research
Field Services
Fisheries
Support Branches
Operating Branches

Figure 2 - Organization Chart for DRR

based upon similarity of construction, content and function. It also addressed the dynamics of the organization by developing a model of information flow within DRR, and between DRR and other organizations. This model would help later on when evaluating alternative computer system architectures. Figure 3 provides a diagram of interaction involving spatially referenced data between the Department Sections.

A description of user applications using DRR terminology was also provided. This was then converted into a listing of GIS functional requirements. The section finished with a discussion of user expectations, organizational issues, cooperation with other agencies, and risks.

Step 2: Generation and Evaluation of Alternatives

Once the User Requirements document was accepted, the second step, the generation and evaluation of alternatives, could begin. The optimal alternative was selected by addressing two key issues: organizational matters, and the computer system architecture.

Organizational Alternatives

The organizational analysis dealt specifically with the operation and structure of DRR, and how the Department might be modified to accommodate the unique needs of the RLIS. Because of its importance, the organizational issue was dealt with first.

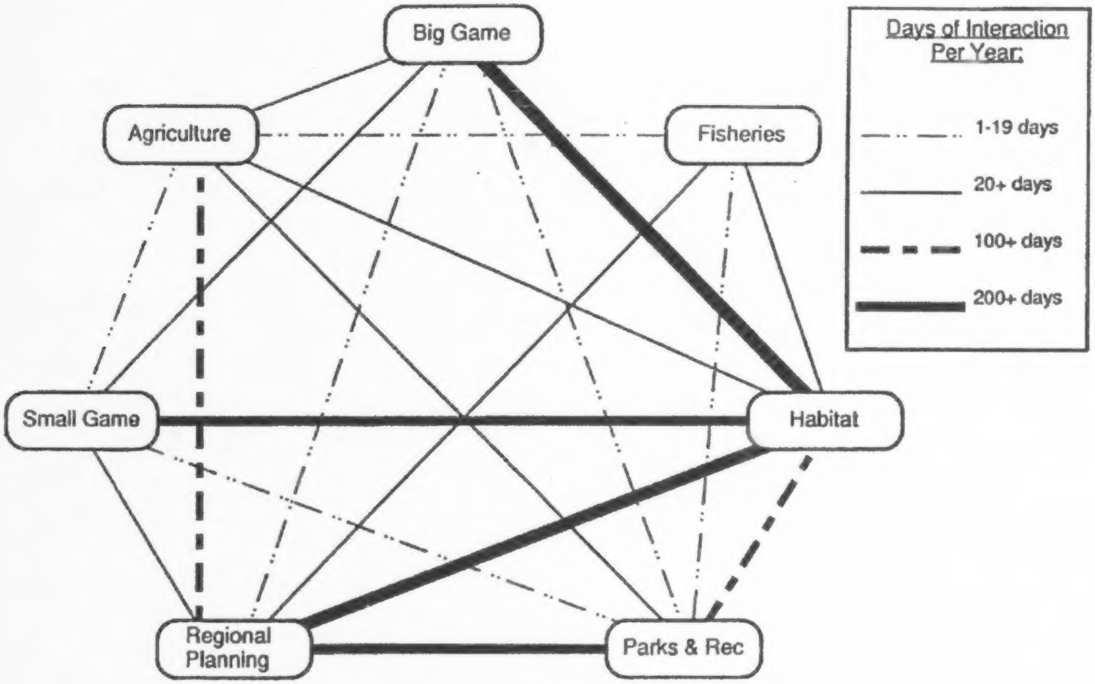
Big Game
Agriculture
Fisheries
Small Game
Habitat
Regional Planning
Parks & Rec
Days of Interaction Per Year:
1-19 days
20+ days
100+ days
200+ days

Figure 3 - Interaction Between DRR Sections

The decision as to which organizational structure to migrate towards was made with minimal consideration of the system issues. While it is true that new technologies will modify organizations, it is important to avoid allowing technology to dictate the structure of the Department. Two key concerns were addressed: the responsibility for database design within DRR, and the type of organizational support that would be provided to the RLIS users.

Responsibility for Database Design

In the Requirements Definition step, a large number of spatially referenced datasets were identified. These datasets are currently designed and maintained within the Sections. DRR had to decide how to assign the responsibility for designing the digital versions of these databases. Two options were presented: an independent approach, where each Section designs their own databases and applications, or a cooperative approach, where the Sections pool resources to develop a common database specification.

Organizational Support

Once the GIS is fully operational, a support organization must be in place to provide a number of services, such as operational support, software maintenance, database maintenance, system backup and retrievals, applications development and user training. Two options were presented: centralized support (pooling of support staff and equipment) or decentralized support (each Section supports their own workstations).

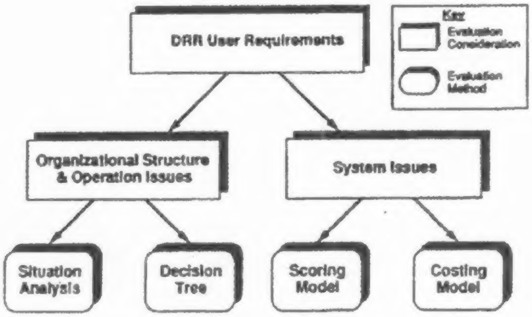
DRR User Requirements
Key
Evaluation Consideration
Evaluation Method
Organizational Structure & Operation Issues
System Issues
Situation Analysis
Decision Tree
Scoring Model
Costing Model

Figure 4 - Evaluation Considerations and Methods

Evaluation Process

The two pairs of options were combined into four organizational alternatives. The selection of the optimal alternative was made by performing a situation analysis. The following issues were considered:

- meeting organizational goals;
- support for individual users;
- impact on the organization;
- cost effectiveness;
- risk reduction;
- flexibility; and
- feasibility.

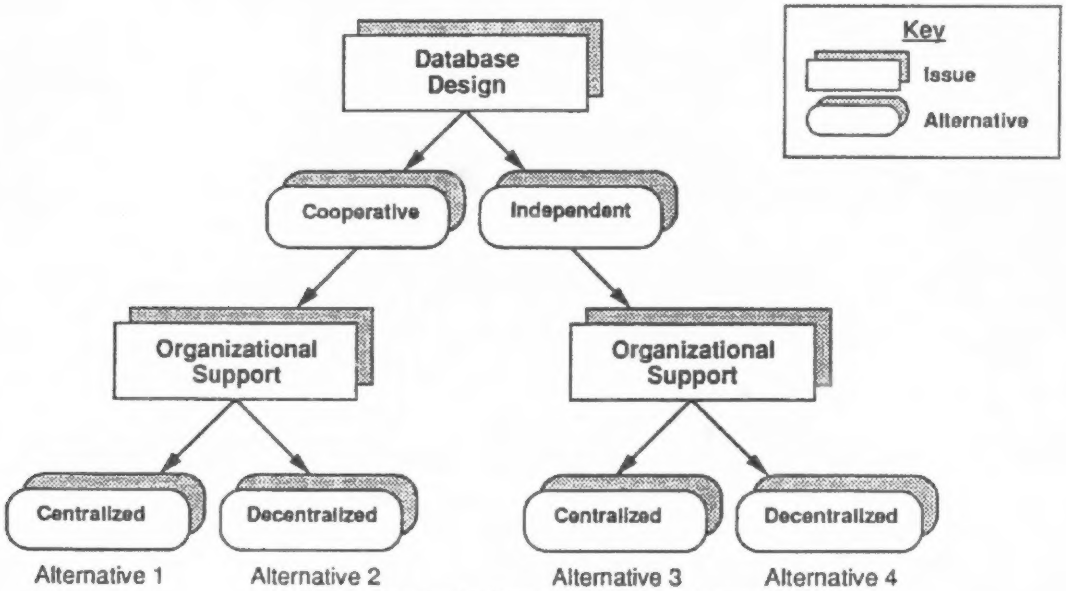
Key
Issue
Alternative
Database Design
Cooperative
Independent
Organizational Support
Organizational Support
Centralized
Decentralized
Centralized
Decentralized
Alternative 1
Alternative 2
Alternative 3
Alternative 4

Figure 5 - Decision Tree Showing Organizational Alternatives

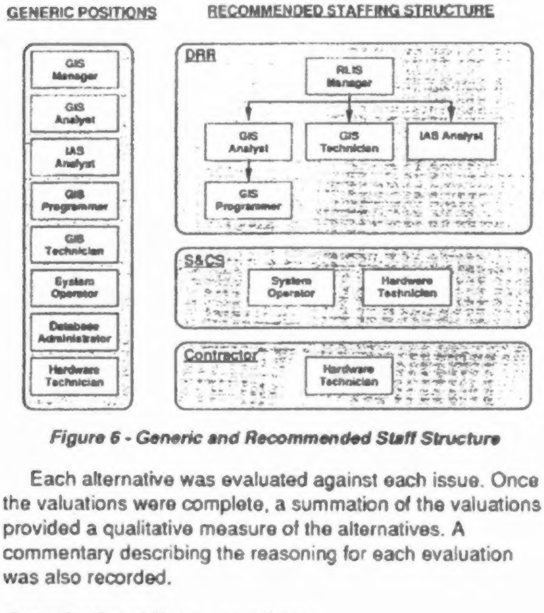
GENERIC POSITIONS
RECOMMENDED STAFFING STRUCTURE
GIS Manager
GIS Analyst
IAS Analyst
GIS Programmer
GIS Technician
System Operator
Database Administrator
Hardware Technician
DRR
RLIS Manager
GIS Analyst
GIS Technician
IAS Analyst
GIS Programmer
S&CS
System Operator
Hardware Technician
Contractor
Hardware Technician

Figure 6 - Generic and Recommended Staff Structure

Each alternative was evaluated against each issue. Once the valuations were complete, a summation of the valuations provided a qualitative measure of the alternatives. A commentary describing the reasoning for each evaluation was also recorded.

Organizational Recommendation

After much consideration and discussion with the Steering Committee, Alternative 1, the cooperative database design with centralized support, was selected as the optimal organizational alternative.

Operational Staffing Structure

Once the organizational alternative was selected, the staffing implications for DRR could be addressed. Based upon a generic set of roles and responsibilities, a recommended RLIS support staff structure was produced. Since the complete structure would only be required once the whole RLIS was in place, an evolutionary path for developing the staff was also provided.

System Alternatives
Evaluation Process

In comparison with the first issue, the selection of the optimal system architecture was more complex. A four-step process was followed:

1. An initial list of GIS alternatives that might be candidate solutions were enumerated using two recent surveys of GIS vendor capabilities. The alternatives provided a variety of combinations from the following: fourteen GIS vendors, four types of computer platforms, and four communications options. The data storage requirements were also estimated to gauge the size of the system required.

2. The initial list was culled down to two platform alternatives; PCs and workstations, and three communications alternatives; no network, within building network, within and between building network.

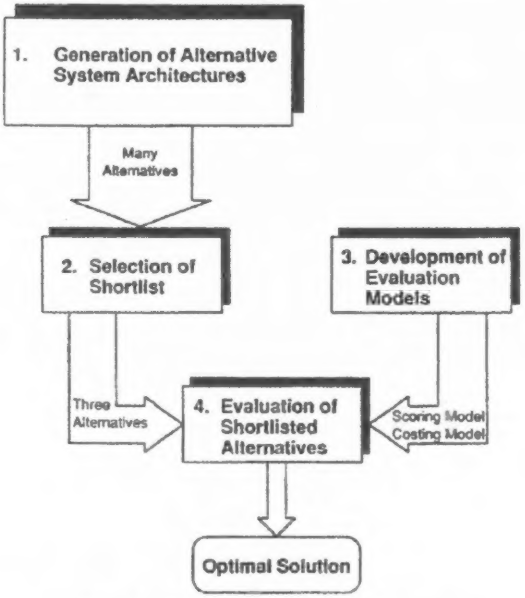
1. Generation of Alternative System Architectures
Many Alternatives
2. Selection of Shortlist
3. Development of Evaluation Models
Three Alternatives
4. Evaluation of Shortlisted Alternatives
Scoring Model
Costing Model
Optimal Solution

Figure 7 - Four-step system evaluation process

Given a set of simplifying assumptions, a set of three generic system alternatives was created: (1) all stand-alone PCs; (2) networked-PCs; and (3) networked-workstations. These options were used to bound the problem: the final solution might actually be a combination of these three alternatives.

3. Given the three alternatives, an evaluation framework was developed. This framework was divided into two parts:
   a. To evaluate the ability of each system to meet DRR's functional requirements, a *scoring model* which exhaustively described the user, hardware, software and operating requirements was developed.
   b. To evaluate the ability of each system to meet DRR's budgetary requirements, a *costing model* which addressed purchase and system maintenance costs was developed.
4. Given the two models, the team evaluated the alternatives and selected the optimal solution.

Scoring Model

Two requirements must be met by the scoring model in order to properly evaluate the system alternatives:

1. The needs of DRR must be documented in a balanced and complete manner with no duplications;
2. The needs must be contained in a structure that is easily understood and manipulated by the Steering Committee.

Using the User Requirements report as a source document, a set of user needs were extracted and organized into a large table with the following categories:

1. General Items;
2. User Data and Applications;
3. Organizational Items;
4. System Specification:
   a. General;
   b. Software;
   c. Hardware;
   d. Communications;
5. MIS Items; and
6. Miscellaneous.

Each need, called an evaluation factor, was labelled as one of four broad types: selection criteria, risk, constraint or issue. These factors were then assigned a unique identifier such as CRIT01, RISK13 or ISSU22. In total, over 150 different evaluation factors were identified.

Given the long list of evaluation factors, a mechanism to facilitate the evaluation had to be devised. This was done by developing a computer-based scoring model which allowed each system alternative to be scored against the evaluation factors. The model used a scoring and weighting system that was easily used by the non-technical user. This system also provided the ability to weight scores within and between categories. Only criteria and risks can be scored: constraints are used to reduce the 'solution space", and issues cannot be scored and are addressed separately.

For each evaluation factor, the consultant assigned a score on a scale which characterized the ability of the alternative to meet that need. Once each alternative was scored, the weightings for each evaluation factor and each evaluation category were assigned by the Steering Committee. With the scores and weightings assigned, the model calculated an overall score for each alternative. The optimal solution is usually, although not always, the one with the highest score.

Costing Model

Two types of costs must be estimated when evaluating the cost of the system alternatives: hard costs (e.g., hardware and software purchase costs), and soft costs (e.g., ongoing data and system maintenance). Given the list of hardware and software components developed for each alternative, a set of cost models which contained entries for quantities, unit prices of system components, and monthly maintenance costs was developed. The model could quickly provide estimates of system and operating costs for various combinations of system components.

System Recommendation

Using the two models described above, the three system alternatives were evaluated. The recommended system was a combination of Alternatives 2 and 3: a heterogeneous system combining workstations and PCs . In addition to the scoring and cost considerations, this selection was made for the following reasons:

1. The proposed configuration is becoming the dominant architecture in the GIS industry. The key consideration here is to try to predict where the platforms will be when DRR actually orders the equipment, not where the technology is today.
2. DRR can establish a 'backbone' using more advanced workstations, and still take advantage of affordable platforms.
3. The solution minimizes the technical risk to DRR.
4. Many vendors offer solutions on the two platforms, thus raising the possibility of finding a good technical solution for a fair purchase price.
5. The architecture provides DRR with an evolutionary path.

Step 3: Implementation Planning

Once the organizational and system alternatives were selected, the third step was to develop an implementation plan. A number of key issues were considered when developing this plan including:

- staffing;
- schedule;
- budget;
- tasks and deliverables;
- assumptions;
- productivity tools; and
- parallel activities.

Each of these aspects is discussed below.

Implementation Project Staffing

The implementation of the RLIS will require a variety of specialists including GIS analysts, systems analysts, GIS programmers and an IAS (Image Analysis System) analyst. The implementation plan provided a clear statement of the requisite skills, project or operational experience, roles and responsibilities for each position.

In addition to these specialists, a number of management positions were also identified including: RLIS Project Manager, Systems and Computing Services (S&CS) Project Manager, and Project Administrator:

RLIS Project Manager: This person will be responsible for the overall supervision of the implementation project and the ongoing management of the system once implementation is complete. The Project Manager will perform strategic and operational planning, manage in-house personnel, and interact with outside agencies. This person must be familiar with the functioning of the Department and is therefore a DRR employee.

Project Administrator: This part-time position reports to the RLIS Project Manager and will be responsible for the administrative, coordinating and clerical tasks associated with GIS implementation. This person will monitor the progress of the project against pre-defined schedules and budgets.

S&CS Project Manager: Because DRR has access to computer systems skills as part of the Government of Yukon, an S&CS Project Manager was also added to the team. This manager will ensure that all aspects of the process are carried out to S&CS standards. This person will also advise DRR on MIS issues.

Two committee structures were also defined: a Project Steering Committee and a Data Standards Subcommittee. The Steering Committee will function throughout the implementation process to provide user guidance to the implementation team. The Data Standards Subcommittee will define, monitor and enforce data standards for the RLIS.

Project Schedule, Tasks and Deliverables

Using a standard software system life cycle as a starting point, a customized project work breakdown structure was developed for the three remaining implementation phases. Each phase was broken down into a sequence of tasks. Each task was described in full detail including a task description, list of deliverables, time estimates for each team member, elapsed time and disbursements (travel and living, materials costs).

Once all of the tasks were described and estimated, they were organized into a project schedule that included a Gantt chart and a list of project milestones. The development of this schedule was done using a PC-based project planning tool. Without the use of this tool, it would not have been possible to cost-effectively develop the schedule, evaluate various staffing strategies, or fit the schedule into outside timing constraints. Because the schedule was in softcopy format, it was also straightforward to use it as an input into the project budgeting process.

Implementation Project Budget

To produce a set of costs for budgetary planning purposes, the implementation and operation of the RLIS was divided into five cost models: implementation costs, system costs, operating and maintenance costs, data conversion costs, and an overall cost model, which integrated the first four models. Each model was comprised of one or more spreadsheets with a set of standard plots and tables to assist in interpretation of the data. The model produced cost information for the first six years of the RLIS system life.

In order to provide DRR with an 'expenditure envelope', two alternative costing models were run: a Minimum System and a Maximum System. The expenditure envelope helped DRR to understand the scope of the funding requirements and to make trade-off decisions between expenditures and system capabilities.

Other Issues

Other issues that were addressed in the planning stage included:

Assumptions: A key part of the implementation plan was the Assumptions section which documented all decisions that were made regarding budget, schedule, staffing and contingency factors. For example: budget assumptions might include the expenditure curve for data conversion; a staff assumption might describe how many staff members will be trained per quarter; a contingency assumption might state the possible affect of GST or inflation on the project costs. If conditions change, the RLIS Manager can revisit this section to determine how a change in an assumption will affect the project.

Productivity and Analysis Tools: To ensure a successful implementation process, DRR will need to make use of a number of computer tools. A section in the plan outlined how the Department could make use of project management and Computer Aided Software Engineering (CASE) tools to improve project productivity.

Parallel Activities: A number of parallel activities will also be undertaken as part of the implementation process including staff training and recruitment, pilot projects and operation of the Steering and Data Standards Committees. A detailed description of each of these activities was also provided in the plan.

Step 4: Management Presentation

Throughout Phase I, DRR management was kept informed of the project schedule and deliverables. For major project milestones, in-house presentations were provided for the senior managers.

Once the RLIS Implementation Plan was completed and accepted, the fourth and last step in this process was to develop a policy document for senior management such as the Minister, Deputy Minister, and funding committees within the Government of Yukon. This material was used to support the Department's application for project funding for the next three implementation phases.

The writing of this document required a change in perspective since the manager's view of new technologies is very different from the user's view. The document was organized into the following sections:

- motivation for acquiring an RLIS;
- work accomplished to date;
- the proposed implementation plan;
- benefits to the Yukon people; and
- complementary GIS activities in Western North America.

The benefits section was the most important part since it described how the RLIS would contribute to Government goals as outlined in the Yukon Economic Strategy, the Yukon Conservation Strategy and the Yukon Tourism Action Plan. Potential benefits were identified in agriculture, fishing, forestry, mining, infrastructure development, technology transfer, environmental assessment and economic development, environmental protection, and national and international commitments.

The last section described complementary GIS work currently ongoing both within Yukon and in Western North America (e.g. British Columbia, Alberta, State of Alaska, Washington State). This was important to DRR, since a smaller territorial government like the Yukon Government cannot afford to lead the pack with new technologies.

In conjunction with the policy document, a highly polished set of colour overheads were also produced for making presentations at various information meetings.

Commentary

The following comments can be made about the process that was followed to produce the RLIS implementation plan:

Requirements Analysis:

- One of the key goals of the project was to raise the GIS knowledge level of the users to allow them to contribute to the planning process. A major benefit of the requirements definition activity is that it raises interest in the user community and starts the training process.
- The requirements definition step focused on data before functions. This was done because it was more straightforward to identify the data sources and results (e.g., maps), and it was difficult for the users to express their current methods of data analysis in an algorithmic manner.
- During the data gathering task, the preview and explanation of the questionnaire at the one-day workshop was critical to getting good answers. The users felt that they were better able to understand the intent of the questions, and had sufficient time to gather information and consider their responses.
- An attempt was made to have the users document their functional needs using a simplified version of process diagrams. These diagrams would have been decomposed and normalized into a list of functional requirements. This process was not successful for two reasons: many users typically do not think about their day-to-day activities in that way; and there was insufficient time to educate the users about the process.
- Although it is difficult for non-GIS users to provide a vision statement about how the technology will help them, the assessment of user expectations was a

valuable exercise. The GIS consultant must be very proactive and supportive when gathering user requirements. We feel that this process must be driven by consultants who understand the user applications rather than systems analysts. A knowledgable applications expert can help users express their needs in their own terms, and can more readily identify gaps in the requirements document. That is not to say that software analysts are not required: their skills are indeed important later on in the implementation process.

- The assessment of user skill levels was a useful activity since it provided an excellent view of the current capabilities and comfort levels of the user community.
- The user community felt that their high level of involvement through the Steering Committee was a key to the successful completion of the first phase of the project.

Alternatives Analysis:

- The major challenge of this step was to structure the organizational and technical issues in a form that helped the Steering Committee which was composed of non-management and non-technical users, to make decisions. If the user comfort level is not high, then the consultant must visit and re-visit issues until the client is able to make decisions with confidence.
- The computer-based costing and scoring models allow the consultant to cost-effectively organize the data and to respond to DRR's needs. For example, the process of evaluating various system architecture options required costing models to be run over and over again under various assumptions.
- The alternatives analysis process recommended a system architecture: it did not select a GIS vendor. It was not reasonable to pick a vendor at this point since the user requirements were only defined to a level sufficient to support the alternatives analysis and planning activities. The next project phase will revisit the requirements specification to further refine it into a clearer statement of user needs. Only then will DRR be in a position to select the appropriate vendor.

Implementation Planning:

- Because there are many systems life cycle approaches on the market today, there is a danger of taking a cookbook approach to planning the implementation process. It was important to customize the process to meet the specific applications, staffing, organizational and budgetary requirements of DRR.
- The computer-based costing model was an important tool for the implementation planning step because it allowed the project team to iterate through different scenarios by modifying quantities and assumptions such as inflation, maintenance charges, etc..

Management Presentation:

- During the writing of the policy document, an unsuccessful attempt was made to quantify the benefits of the RLIS in dollar figures. While it was possible to identify real benefits, DRR could not quantify them.
- A possible pitfall of the management presentation is the EE (Executive Excitement) syndrome. There is a danger of getting senior management excited about the potentials of the technology too early in the process. The RLIS Project Manager will have to balance management expectations with the long timelines that are typically associated with the GIS implementation process. This issue can be partly addressed by running a series of pilot projects in parallel with the implementation process to produce near-term results.

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The Role of GIS in Integrated Resource Management for First Nations Initiatives in Alberta

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Abstract

GIS technology affords the ability to integrate a wide range of environmental, demographic, and economic information in the support of resource management initiatives. MINSTIK Developments Ltd. is a 100 % Treaty Indian-owned company whose mandate is to develop and deliver GIS capabilities for First Nations resource management initiatives. However, the realization of these application opportunities requires a focused and planned strategy based on a clear understanding of the market potential, implementation requirements, technical alternatives, and risks associated with such a comprehensive venture.

In order to proceed with this mandate, we are undertaking a comprehensive assessment of the First Nations market potential in combination with a review of appropriate technical strategies. The result of this feasibility study is a business strategy that focuses on implementing and applying GIS in a manner appropriate to meet the needs of Native organizations. This paper presents an overview of the methods, issues, and activities involved in this study. A review of MINSTIK's implementation and development strategies is provided, including approaches utilized for dealing with cultural and technology transfer issues. A review of preliminary results from the initial pilot project activity is also included.

Introduction

GIS technology affords the ability to integrate a wide range of environmental, demographic, and economic information in support of integrated resource management initiatives. MINSTIK Developments Ltd. is a 100% Treaty Indian owned company whose mandate is to develop and deliver GIS capabilities for First Nations resource management initiatives. MINSTIK has been established with the objectives of providing technical support and related technical services to First Nations and other similarly interested groups and government agencies. Four general goals form the core of MINSTIK's business objectives. These are :

- to develop a suite of products and services which can be effectively applied to Native Band resource management;
- to develop these products within the context of a 100 % native owned enterprise;
- to focus on First Nations as a target national market; and
- to establish and implement a planned and deliberate strategy for business development.

It is MINSTIK's focus to develop customized geographic information systems (GIS) in combination with associated automated mapping and facilities management (AM/FM) decision support systems within the context of the general goals.

To facilitate these objectives, some specific value added products and services will be emphasized. These reflect the immediate need of First Nations in support of integrated resource management. These include :

Products

- Integrated resource databases;
- Geographically based application systems for resource management;

Services

- custom data compilation, as part of the development and/or updating of databases;
- development of custom resource information management systems using commercially available GIS, AM/FM, and database management systems (DBMS);
- training of personnel for the custom systems; and
- installation and on-going technical support.

MINSTIK has over twenty years experience dealing within the First Nations infrastructure with an emphasis on the planning and management process focusing on social issues, education, housing, management of assets, program and resource management, and Band administration. Currently, MINSTIK principals are involved in consulting to the Tribal Chiefs Association of northeastern Alberta, its five member bands and the Department of Indian and Northern Affairs. It is expected that this experience will be instrumental for the successful implementation of automated decision support systems within the First Nations context.

Background on First Nations Requirements and Strategies

In order to operate and survive as self-governing political nations, Indian bands must first and foremost develop an economic infrastructure to sustain their political institutions. To achieve this, it is imperative that economic resources be identified and a resource management strategy be developed and implemented.

In the past, First Nations have lacked the information, automated tools, and expertise to effectively management their resources. To date, the land base of the Treaty Indian reserve has been excluded from most information management programs. This is especially true at the provincial government scale of data inventories. This has perpetuated a dependence on externally planned, implemented, and controlled programs and services.

The existing Treaty Indian Reserve infrastructure is supported with capital, operational and maintenance costs incurred by the Canadian government's Department of Indian and Northern Affairs, as part of Treaty obligations and commitments. The nature of information capture and management within this political structure often neglects the Band's planning needs and desires. This situation is not a result of intended neglect, but exists due to imposed political and financial architectures within the Federal bureaucracy. Existing Indian Affairs databases operate on a stand-alone basis, supporting cooperative administrative functions rather than internal Reserve planning activities. As well, most of this data is not captured or structured in a manner that will support geographically based analysis. It is maintained in conventional data processing systems designed to support conventional data processing activities.

Accordingly, the data available to Band councils for internal planning often does not meet their information requirements. As well, much of the research done in Treaty Indian Reserve lands is not intended for the Reserve communities use or even made available to them. This imposed dependence on Federal government programs and activities has resulted in pressures and barriers to accessible and accurate geographically referenced data.

In response to these problems and constraints, MINSTIK, with the financial support of the Federal government's Industry, Science and Technology Canada, Aboriginal Economic Programs, has initiated market activities focused on investigating the use of GIS technology to address these issues. Much of the motivation for these activities has been the frustration at the Band level, based on their inability to utilize and implement integrated resource planning strategies.

Many of the principles of integrated resource planning are consistent with the cultural traditions, customs, and practices of the Native community. Integrated resource planning attempts to ensure that decisions made about the development of Alberta's land based resources are reached cooperatively and take into account all resource uses and needs. This philosophy emphasizes planning based on a multi-sector approach by securing a favourable mix of land uses to achieve maximum benefits. No one land use activity, be it mineral development, timber harvesting, or agricultural, is emphasized. The comprehensive nature of integrated resource planning requires the use of economic, social, and environmental data. Wise management requires a rational attitude relying on a range of information sources. This approach involves three rational steps; data collection, the selection of appropriate actions to meet planning objectives; and the implementation of decisions. The planning process must also be dynamic and flexible; it must be able to respond to changing needs at any stage of the planning process.

The integrated resource planning strategies focus around the ability to integrate data from a wide variety of different sources. One of the problems associated with this approach to date has been the compilation of data and the inherent complexity of analyzing possible development and land use alternatives. GIS technology provides the capability to address these data and analysis issues. The integration and analysis of spatial data are the key functions provided by GIS technology. However, it should be noted as a forewarning, that with the numerous application opportunities, there exists the reality of underestimating the work, time, experience, knowledge, and costs involved in the development, implementation, and maintenance of a GIS database.

GIS Implementation Strategies

In order to effectively address the many sophisticated issues involved in implementing and applying GIS technology in the context of MINSTIK's objectives, a detailed understanding of market, business, and technical strategies is required. One method to obtain this information is to undertake a market assessment and feasibility study. This will ensure that critical First Nations issues, such as data availability, are addressed with appropriate business strategies. The result of this feasibility study is a business strategy that focuses on implementing and applying GIS in a manner appropriate to meet the needs of Native organizations. A review of the activities required are presented below.

Market Potential Assessment

The market potential assessment involves an analysis of relevant market issues with respect to market profile, market penetration opportunities, the role of technology, and critical success factors. These activities are undertaken to obtain a clear understanding of the current industry and its market potential. In particular, identification of the role of GIS technology in the private, provincial and federal government sectors is required. This allows MINSTIK to focus its energies on providing services and products in a manner appropriate with market needs and activities. A review of the major tasks required in market potential assessment is appropriate.

Market Profile and Analysis

This phase of the market assessment focuses on defining the resource management industry by providing a market profile. This task quantifies the industry by identifying existing market parameters such as the types of services, products, firms, and gross revenues. This task focuses on identifying existing service and product offerings by the major firms, including both software vendors and consultants firms. An emphasis on the identification of specific skills and expertise related to implementing and applying GIS technology is stressed. This is important as MINSTIK expects to make extensive use of appropriate firms in the provision of their services and products.

Potential Customer Profile

The second phase of the market assessment focuses on identifying potential customer profiles. Considering the goals and objectives previously identified, a detailed market survey is required of First Nations in Alberta. This involves presenting a realistic application developed with existing GIS software to illustrate the potential of the technology. This application is developed around integrated resource planning strategies that illustrate several different land use alternatives while emphasizing decision making support through information integration. Data was compiled from federal and provincial government and private industry sources. A further discussion of the marketing pilot is presented later on in the paper. In support of longer term market considerations, a nationwide First Nations survey is also required. This provides a general overview of potential market opportunities across Canada.

Business and Technical Strategies

The application of GIS technology will provide opportunities to protect and enhance constitutionally affirmed and entrenched obligations to the historical, linguistic, and cultural traditions of treaty Indians and lands reserved for Indians. These opportunities provide an exciting possibility to address constraints imposed by the Indian Act legislation of economic development and resource management initiatives for treaty Indians. MINSTICK Developments Ltd. is dedicated to ensuring that these opportunities are not ignored.

Review of Technical Strategies

A review of technical strategies requires consideration of a range of different concerns. These include staff training, pilot project planning, hardware and software acquisition, and data acquisition. Perhaps the most important task is the assessment of related software such as GIS, AM/FM, and DBMS. As identified the success of a GIS installation is often dependent on the matching of technical requirements and software functionality. The right choice will be the GIS that provides the needed performance no more, no less, for the minimum investment. GIS implementation success is particularly sensitive to the right hardware and software choices.

A high level assessment of GIS and AM/FM software offerings requires consideration of several factors. Of most importance is the evaluation of functional capabilities. This should include a review of all typical GIS subsystem functions, weighted by importance as defined by user requirements. However, GIS software offerings should not be evaluated by specific functions alone. Consideration of subjective technical factors such as user interface, help utilities, documentation, training and support, company risk assessment, technical excellence, and environmental issues, such as performance, space, speed are also important. And to make the assessment even more complex, consideration of general systems characteristics is especially necessary when considering the changing hardware platforms that are available. These characteristics include factors such as supported hardware platforms, operating systems, DBMS interfaces, adherence to computing standards, application programming interfaces (API), and spatial data structures. It is clear that the importance of this task requires an experienced GIS consultant who has had significant hands on experience with several software offerings. This step of the technical assessment can be critical to the success or failure of the GIS implementation.

Development of a Business Strategy

The development of a business strategy rationalizes the results of the market assessment and technical evaluations providing a solid foundation with respect to the financial, administrative, and management structures essential for a successful business venture. This includes a definition of the capital requirements in terms of fixed assets, operating capital, anticipated expenses, and revenue budgets. It also requires the definition of the human, technical, and resource requirements of the venture. Consideration should be given to data compilation requirements, if appropriate. It is generally accepted that data costs typically make up 60 to 70 % of the total cost of the GIS investment. This percentage may differ considering available data sources, level of data accuracy required, and the expertise of GIS operating staff. Definition of the management requirements is also necessary. This should involve identification of the company structure and administrative support sector.

User Needs Analysis

A vital part of any GIS implementation process is the identification of user needs and related technical issues. This is commonly referred to as user needs analysis. Within the context of First Nations initiatives, the user needs analysis assists Treaty Indian leadership in the recognition of complex and dynamic problems, generated by a diversity of human, natural resource, infrastructure, financial, and political factors. This analysis should identify all specific information products and the data that are needed by Band personnel. Definition of both report and map products is necessary. Of critical importance is the prioritization of all information products and associated data requirements.

A user needs analysis was undertaken by MINSTIK for a specific Reserve in north eastern Alberta. Beaver Lake Indian Reserve (No. 131), located near Lac La Biche, Alberta, approximately 220 kilometres east of Edmonton, served as the study area for the pilot project activities. The Reserve is home to over 350 Treaty Indians encompassing an area of approximately 15 000 acres (6080 hectares).

The first step in the user needs process was to compile an inventory of the geographic area of the reserve. This included compiling all existing information related to locational surveys, geologic, climatic, and land use characteristics. A summary report was generated identifying the general characteristics of the environment.

The second step involved a review of all information products currently identified and required for Band planning activities. These products were obtained by reviewing Federal government development funding and plan requirements. A survey was also undertaken with specific Band members to identify internal planning requirements. These often did not match Federal information requirements.

A review of the Federal government information sources identified five databases maintained by the Department of Indian and Northern Affairs for Treaty Indian Bands within Canada. These databases are designed, developed, and maintained by several agencies within Indian Affairs. It is interesting to note that all five database systems are stand-alone systems. Currently no quality control mechanism is in place to ensure data integrity between them. The five systems are :

- Indian Registry System;
- Post Secondary Education System;
- Nominal Role Information System;
- Community Assets Inventory System; and
- Social Development Information System.

Each system was developed for a specific purpose independent of the other systems. As well, some of these systems are maintained in the regional office in Edmonton while others are maintained at central headquarters in Ottawa. The regional office has remote access to the central databases. Access to Treaty Indian Bands is only available through Indian Affairs regional or central offices. It is our understanding that to date, no data has been requested or distributed to Bands for maintenance, updating, or planning activities.

The user xeds analysis also identified opportunities for GIS applications. These were categorized into 5 groups. Over 41 different applications were identified. These included area and property analysis, management and maintenance of assets, recreation assessment, and more typical GIS applications such as land use suitability, environmental impact assessment, and timber harvesting potential. A review is currently underway to identify appropriate applications for pilot project activities to be addressed in the coming year.

Pilot Project Activities

Based on the initial user needs analysis a small pilot project is currently underway to support market survey and promotional activities. This marketing pilot will address relevant needs of the user needs analysis as well as attempting to integrate the five Indian Affairs databases. Data acquisition and loading is currently underway. The databases are also being normalized in a relational DBMS environment. Enhancements to database tables are being initiated prior to data loading to reflect internal (Band) data requirements as identified in the user needs analysis. Upon completion, these databases will be integrated with the GIS component in an effort to evaluate the useability and feasibility of utilizing this information for Band information management. It is important to understand that these databases merely provide summary information for the reserve areas. They do not provide any value-added information for regional or local issues. The major criticism of these databases by Band members is that they do not provide any information with respect to local concerns.

While this database development is underway, a more typical natural resource application is also being developed. This will involve data from several sources, including private sector, provincial and federal government agencies. As identified earlier, a major concern with Indian Reserves is the lack of coverage for most provincial government resource inventories. There is a wealth of resource based data that has been compiled by Alberta government agencies. Unfortunately, Indian Reserves status as federal lands has hindered the data capture and field checking processes that are normally involved in resource inventories. This has resulted in most Reserve areas being represented as holes on the inventory maps. Investigations are underway with respect to determining appropriate Federal government data sources. Currently, data is being compiled by MINSTIK staff for vegetation cover and wildlife key areas.

One exceptional provincial source is the recent multi-client Alberta Vegetation Inventory (AVI) prototype by Alberta Forestry, Lands and Wildlife. It holds considerable promise for fulfilling some future data requirements. The AVI approach reflects Alberta's philosophy of integrated resource planning by combining the stratification requirements of timber, wildlife habitat, and rangelands together in one vegetation inventory. A recent review of potential data sources indicated that AVI data is available for the Beaver Lake area. Figure 1 presents AVI data for the Beaver Lake Reserve.

The user needs analysis also identified a variety of data requirements that are unique to First Nations application scenarios. The compilation of these data layers require an understanding of Native culture, traditions, and infrastructure. Some of the data layers that require specific consideration include :

- sacred areas;
- burial grounds;
- sweet grass areas;
- traditional gathering areas including berries, herbs, roots, and medicinal plants;
- hunting areas including consideration of deer, mule deer, caribou, bear, etc.;
- traplines (trapping areas);
- fishing areas;
- constraining boundaries (reserve)
- property ownership involving traditional patterns of family areas; and
- camping sites.

Based on the initial results of the marketing pilot and the market potential assessment that is currently underway, a comprehensive pilot project will be implemented within the coming year. The pilot project will result in an integrated resource information system for the Beaver Lake Reserve. The intent of the pilot project will be to test and illustrate the feasibility of GIS technology for addressing First Nations information management problems. Both natural resource and municipal scale issues will be addressed.

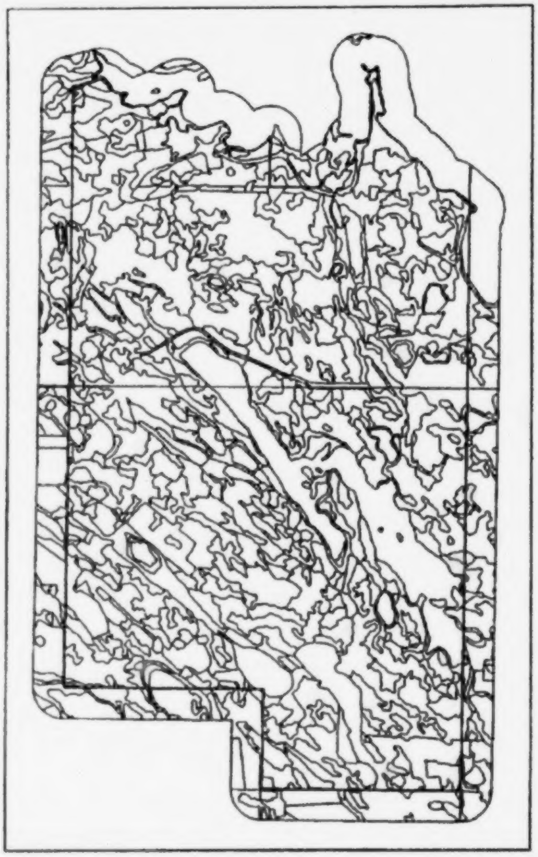

Figure 1. Alberta Vegetation Inventory stands for Beaver Lake Reserve No. 131.

Results and Conclusions

It is clear through the activities that have been undertaken to date, that GIS technology affords many possibilities for First Nations requirements. GIS will not only provide the mechanism to integrate information but it will also enforce the compilation and maintenance of appropriate data. Too much administrative information is maintained that offers little to Native Bands in support of realistic planning scenarios. The pilot project is a crucial step in a successful GIS implementation process. It is a valuable means of assessing progress and identifying problems and specific data concerns early, before significant resources are wasted on production development. The pilot project will also provide an excellent training scenario for MINSTIK staff.

A major issue that must be addressed in the application of GIS technology to First Nations requirements is technology transfer. GIS typically has a steep learning curve.

This must be accounted for in training and implementation strategies based on the specific situations of each Band. It is expected that a significant amount of MINSTIK's resources will be allocated to providing this service.

Another major issue will be the acquisition of data. The nature of Native Band infrastructure presents some interesting issues with respect to the availability and accuracy of relevant data. Many of the data sources are dependent on selected individuals within Bands. Information about property ownership is often passed down through family lines over time. Documentation may not exist describing land or property ownership rights. The compilation of much of this specific data will undoubtedly be labour intensive.

The application of GIS technology presents a unique opportunity for First Nations to become involved in the information capture and management activities currently being undertaken by both provincial and federal government agencies. Data is being compiled, often in digital format, at a rapidly increasing rate. However, Reserve lands are usually excluded from data capture more often due to administrative and political considerations rather than technical ones. It is hoped that the activities of MINSTIK in support of First Nations initiatives can address these issues. Based on interactions and support provided to date it is expected that both provincial and federal agencies will provide significant support.

The application of GIS technology will provide opportunities to protect and enhance constitutionally affirmed and entrenched obligations to the historical, linguistic, and cultural traditions of Treaty Indians and their rights and lands. These opportunities provide an exciting possibility. MINSTIK Developments Ltd. is dedicated to ensuring these opportunities are not ignored.

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GIS-based Habitat Supply Modelling in Northwestern Ontario: Moose and Marten

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Abstract

GIS-based habitat supply models (HSM) will be under strong development over the next few years for areas such as Northern Ontario where land managers are eager to manage for wildlife habitat through an objective- based approach rather than a constraint-based approach. We have built and demonstrated the use of one such model for marten, and are presently doing the same for moose. In this paper, we present a series of principles for the design of GIS-based HSM, and describe how these principles were factored into our models. The principles cover: (a) availability of habitat data; (b) forest dynamics; (c) habitat alteration; (d) habitat assessment units; and (e) proximity of food and cover. We conclude with an outlook on future developments in GIS-based HSM.

Introduction

Wildlife habitat supply analysis and modelling are important new developments in the management of large forest estates in Canada. Strong advances were made in the U.S. in the late 1970s (Thomas, 1979), with further promising work in the 1970s and 1980s with the so-called Habitat Evaluation Procedures and Habitat Suitability Indices (USFW, 1981). Progress in Canada has been significant in the 1980s, including notable work in British Columbia (Marcot et al., 1988), Alberta (Bonar et al., 1990), and New Brunswick (Patch, 1987; Anonymous, 1990), as well as new projects in Ontario (Watt, 1990), including our own described below.

Habitat supply models of a wide variety of types have been reported in the literature. Some models simply rank or rate habitats on scales of goodness, whereas others estimate actual wildlife carrying capacities. A promising classification of HSM looks at the static versus dynamic treatment of both habitat and the wildlife populations of interest. In the static habitat, static population HSM, characteristic of most habitat suitability indices (Allen, 1982; Allen et al., 1987), calculations of habitat rating or carrying capacity are made for current habitat conditions, without regard for the dynamic occupancy of the habitat by a species population. In models of the static habitat, dynamic population type models are calibrated to a specific set of current habitat conditions. Recognizing that over the medium to long term, habitat is a dynamic landscape feature and evolves under natural and human influences, more models that predict habitat dynamics are beginning to appear. Some of these (Martelle, 1990) are dynamic habitat, static population models in that they calculate wildlife carrying capacities independent of dynamic occupancy of the habitat by the species of interest. Others, of the dynamic habitat, dynamic population type (Duinker, 1986; Duinker, 1989), recognize that animal populations do not necessarily respond immediately and linearly to changes in habitat carrying capacity, and try to account for such relationships by linking habitat and population simulators. To deal with spatial relationships in static habitat modelling, and especially dynamic-habitat analysis, a GIS is an indispensible tool.

In our research program we are undertaking exploratory development of dynamic-habitat simulators for two high-profile species in Northern Ontario:

1. Moose (*Alces alces*). Moose are high profile as they are an official featured species in the timber management planning process (OMNR, 1988), and an important game species; and
2. Marten (*Martes americana Turton*). Marten are also high profile as a commercially-exploited fur species and as a good indicator of wildlife population status under conditions where mature and overmature boreal forests are subject to heavy harvest pressure.

Our objective with this paper is to convey several principles of habitat supply modelling that are guiding our work, and to describe how we have accommodated those principles in building our HSM. We conclude with some prognostications about where we see the most promising HSM developments in the 1990s.

Principles for Habitat Supply Modelling, and Some Example Approaches

Habitat Description

Principle 1: A broadly applicable HSM must rely on easily obtained data describing landscape vegetation patterns.

Habitat supply modellers working on research and development projects may have the luxury of time and money to implement detailed site-specific surveys of habitat features and spatial patterns. However, for operational analyses in planning for the typical large forest-management units found across Canada on Crown land, an HSM must be able to calculate wildlife carrying capacities based largely on extant descriptions of the forested landscape. Fortunately, all provincial agencies in charge of managing public forest resources make periodic forest inventories. Unfortunately, the time between successive inventories is often long, some 20 years in Ontario, and the data gathered are timber-oriented, not wildlife habitat-oriented.

In some areas, there are additional extant data sets that may be found useful in habitat supply analysis. In Ontario, a new set of Forest Ecosystem Classifications (FEC; Sims, 1989) is being developed. These FEC include both understory vegetation and soils descriptions. Fortunately, some forest inventories have already been augmented with the understory data, which is key information in both timber renewal planning and species habitat relationships.

Approach

In our work on marten habitat (Martelle, 1990), the forest resource inventory (FRI) for the study area was made available from the forest products company holding the forest management agreement. Ontario FRI provides both an indication of species composition of each stand, in 10% classes for each major species, and an assignment of each stand to a socalled timber working group. We felt that the working groups were too coarse for our purposes, so we reclassified the forest stands, based on the composition data, from 5 working groups into 8 forest classes.

In the moose habitat study, we are also generating more forest classes than there are working groups, but we have the added advantage of FEC vegetation type data for each forest stand in the FRI. These data are assisting us in making estimates of the potential browse availability in each stand type.

Forest Dynamics

Principle 2: A broadly applicable HSM should account for the dynamic evolution of forests on a stand-by-stand basis.

Near-term habitat alterations such as timber harvest and silvicultural activities set the development path for many habitat elements for many decades, even centuries, in some kinds of stands. If we are to take future habitat patterns seriously in forest resource decision-making, the dynamic development of all forest stands, both those treated and those left alone, must be forecast.

Approach

To account for long-term forest dynamics, we are applying the same approach as used in many forest inventory projection tools, namely, stand-level development forecasts. Stand development curves for forest management modelling usually portray wood volume over the full range of stand ages, and are constructed on the basis of empirical evidence, stand simulation, and professional judgement (Duinker et al., 1991). We are developing and using such timber curves in our forest development simulation in both studies, as outlined below. With regard to stand-wise forecasts of habitat value, in our marten study we translated the full range of potential stand ages into three development stages (e.g., young, immature and mature/overmature) to which marten carrying capacities per unit area were assigned (Martelle, 1990). In the moose study, for each stand type and stocking class, we are preparing age-dependent curves of moose browse and cover quality. This exploratory study will not collect new field data for curve construction although we do recognize the clear need to do so once such modelling becomes an operational planning tool. We are gleaning relevant data from the literature, and are canvassing opinions from moose biologists and habitat specialists to help design the curves.

Forest Management

Principle 3: A broadly applicable HMS must be able to accept input of reasonably implementable forest management interventions.

Much of the concern over the status of forest-dwelling wildlife populations is focussed on forests that are managed for timber production. Timber production plans consist of short-term allocations of stands to specific harvest and silvicultural treatments in specific years, and medium-term schedules of further harvest and silviculture activity. The analytical work in habitat supply analysis often begins with forecasting wildlife habitat carrying capacity response to a timber management stategy, and continues if necessary with generating alternative timber strategies to obtain a more favourable habitat forecast. The alternative timber strategies must be readily generated and have a level of implementability on par with real timber management plans. Fortunately, there are several forest simulators available for use in generating timber management strategies.

Approach

In our marten study, we used the FORMAN simulator (Wang et al., 1987) to generate four timber management scenarios to use in forecasting habitat response. FORMAN is fed with classed forest data, and the identity of specific stands is lost. In mapping each timber management scenario, we had to return to the stand-wise data from which we created the forest classes, and manually choose which stands to treat in each simulation period. In the moose habitat work, we intend eventually to use the HSG model of Moore and Lockwood (1990), mainly because it preserves the identity of each stand in the forest throughout a simulation. Thus, strategic simulation can be more readily translated into spatially and temporally explicit allocations of specific stands to treatments. Outputs of our timber management simulations will be fed directly into ARC/INFO for calculations of moose habitat carrying capacity.

Habitat Assessment Units

Principle 4: A broadly applicable HMS must accommodate the fact that many species of wildlife (moose, deer, marten), with home ranges encompassing many forest stands, range freely in hard-to-predict spatial patterns.

In habitat supply analysis for many wildlife species, three levels of biophysical spatial resolution must be dealt with: stands; home ranges; and the entire forest. If we want to depict spatial patterns of habitat carrying capacity across a forest, we must make calculations of that carrying capacity for a suite of habitat assessment units, each of which covers a small portion of the forest. The units ought to be larger than the average home range of the species in question, because the real boundaries of each animal's actual home range can not be predicted,and the concept of wildlife carrying capacity within a unit of land requires the assumption that animals inside the unit cannot go elsewhere if their needs are not fully met within the unit.

Approach

Marten have home ranges from under 100 ha to several hundred hectares (Martelle, 1990). Our marten study used 400 ha habitat assessment units within a 40 000 ha study area. We arranged fixed boundary assessment units into a pattern of 100 (10 x 10) units across the study area. We assigned the calculated marten carrying capacity of each unit to its geographic centre, removed the unit boundaries, and contoured the landscape with isolines of equal carrying capacity for each forest management scenario and time period. The resultant maps show, in a rough way, the distribution of marten carrying capacity across the study area.

Our moose habitat work is taking advantage of an earlier development (Duinker, 1986) with overlapping habitat assessment units. The square units will be just over 2 000 ha (Koppikar et al., 1990), and will overlap by 50% with their neighbouring units in each direction. Our rationale here is to permit each stand to contribute to the calculation of unit-wise carrying capacity several times, reflecting the possibility that moose with home ranges centred at several different and distant places may be making use of the same stand for feeding or cover. We also wanted to increased the density of points across the landscape from which to calculate an area-adjusted moose carrying capacity at the same time as keeping the assessment unit large. Here again, we are assigning calculated carrying capacities for each unit to a point at its geographic centre, removing the unit boundaries, and contouring the landscape with isolines of equal carrying capacity.

Food and Cover in Proximity

Principle 5: Many wildlife species, especially large herbivores, prefer to eat near cover. Therefore, food availability should be tempered by its proximity to cover.

Modelling of habitat for most herbivores must account for both the food and cover requirements of the species under consideration. In addition, it is often important to separate the year into two or more seasons, since the food and cover habits and requirements of some species are rather different at different times of the year. For large herbivores in summer, the cover requirement is often for escape purposes, while in winter it is also for heat regulation through wind blockage, breaks from open sky, and mobility (shallower snow). Under many circumstances, large herbivores do not venture long distances from cover to feed, suggesting the importance of stands that can provide both food and cover and those edges between stand types that primarily provide cover and those that primarily provide food.

Approach

Marten are mainly carnivorous, with the main diet items comprised of voles and mice. Marten prefer to inhabit late successional forest stands with strong proportions of coniferous species (Martelle, 1990). In our rather unsophisticated marten HSM, we ignored potential edge effects on habitat carrying capacity, and rated all stand types with independent, type-wise carrying capacities in terms of number of marten per square kilometre. Our justification for this treatment of marten habitat is that, in winter, marten may be expected to find denning sites, non-den cover and food all within the same mature/overmature coniferous stand types.

In our moose work, we are calculating carrying capacities for three seasons: spring/summer/fall; early winter; and late winter. Because so many different stand types and ages serve moose well as non- winter escape cover, and stands in Ontario's boreal forest are seldom monolithic, calculations of non-winter carrying capacity account for food supply only. In late winter, moose are generally not eating much, and are biding time under the best thermal-regulatory cover available until spring. Therefore, the carrying capacity calculations for late winter account only for cover.

For early winter carrying capacity, we are making food calculations that are adjusted by the quality of cover at or near the location of interest. To accomplish this, we have gridded the landscape with a set of points 200 m apart, and assigned to each point the characteristics of the stand in which it falls (Koppikar et al., 1990). Then we ignore stand boundaries, and let each point represent 4 ha of the landscape. Preliminary food calculations are made for each point with relationships that reflect stand composition, stocking and stand age. The cover quality of each point is rated on a scale of 0 to 1 with relationships reflecting stand composition, age, stocking and height. Our model takes a look at the cover indices of the point of interest and its eight nearest neighbours, as the point of interest is in the centre of a 3-by-3 set of points, and multiplies the food supply for the point of interest by the highest cover index found among the nine points. A point may lie in a stand of high food value and low cover value. If all its neighbouring points are also of low cover value, its food contribution to carrying capacity will be shifted down to reflect that it is neither in nor near good cover. However, if one of the neighbouring points is in a stand of high cover value, then the point of interest will contribute strongly to early winter habitat carrying capacity. This reflects a conventional wisdom that edges between cover stands and food stands represent suitable habitat for moose in early winter, whereas the centres of large openings in clearcuts, burns or barrens do not.

Conclusions

We believe that a proper integration of timber and wildlife goals in the management of large forest estates will not occur unless GIS-based habitat supply analyses are routinely undertaken. The first major developments in habitat supply models will likely be that those presented so far as static models will be converted to dynamic habitat models. Fortunately, this will be a relatively straightforward transformation. It will reflect the fact that habitat conditions created in the near term by immediate timber harvest and silviculture activities will not be the same in the long term. Moreover, habitat conditions in the long term may be as strongly influenced by today's timber harvest and silviculture as by future activities.

Subsequent, and more difficult, developments will include: (a) the attachment of dynamic population simulators to habitat simulators, particularly for the purposes of exploring interactions among habitat influences on animal populations and influences of other factors such as winter weather, predation, hunting, and disease; (b) the preparation and use of habitat supply models for the full range of vertebrate wildlife species occupying forest landscapes, first for better known species and subsequently for species for which considerable research on species-habitat relations must first be undertaken; and (c) the efinement of habitat models so that fine-scale habitat features and species-habitat relations can be used in forecasting carrying capacities over large landscapes, rather than simply using broad landscape indicators. The use of a GIS here will permit sophisticated mapping of the distribution of wildlife carrying capacities across such landscapes.

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An Integrated National Land Resource Coverage: New Zealand Experiences

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Abstract

A national coverage of land resource information at a consistent scale serves as the information base for interpretative applications addressing the fundamental issues facing the regions of New Zealand. We use three case studies to demonstrate the benefits of compiling an integrated national land resource coverage.

A proposed on-land disposal of sewage waste was modelled according to several waste discharge scenarios for the rural lands adjacent to New Zealand's largest city. The results of this study were used as the basis for selecting between other waste disposal options and any eventual site selection.

In some regions of New Zealand, the introduced rabbit is an agricultural pest. Modelling of the rabbit's preferred ecological niche was used as the basis for strategic planning, pest control measures and land rating schemes.

Implementation of an evaluation system for crop production on the Canterbury Plains, New Zealand, will be detailed. The evaluation system has been built to evaluate land (map units) from on-farm to regional sites. The system has several components: a knowledge base describing proposed land uses, both in physical and economic terms; a database describing the land areas being evaluated; and an inference mechanism to relate these two, thereby computing the physical and economic suitability for crop production. Management scenarios can be evaluated to optimize and assess gross margin, net return, costs and yields.

Introduction

The New Zealand Department of Scientific and Industrial Research (DSIR) Land Resources has been using in-house and commercial GIS software for almost two decades. A national programme for survey and digital storage of land resource information was undertaken in the early 1970s. The New Zealand Land Resource Inventory was the first national coverage of digital spatial data in the country. Other parts of DSIR Land Resources were similarly involved in pioneering research and applications in GIS, image processing remote sensing and digital cartography.

Other New Zealand Government agencies have also been compiling digital spatial databases and New Zealand is in an unique and enviable position of having complete national coverages of land-based information including land resource, topographic detail, cadastral, statistical and valuation data. However, the resolution of the information varies between data sets. The use of GIS technologies within each of the major data contributors has opened the door to integration and applications previously considered too difficult to attempt.

A national land resource survey, at 1:63 360 compilation scale, resulted in the production of the New Zealand Land Resource Inventory (NZLRI) which is a series of 320 map sheets covering some 260 000 km^2. Information systems for storage, retrieval and output were developed concurrently with the national survey.

The NZLRI has a very simple implementation of GIS technology, in a database sense, and is stored as a multifactor database with five core attributes, soil, rock, slope, erosion, and vegetation attached to a set of polygons which represent geomorphic units with similar potentials or limitations to productive uses. This is known as the Land Use Capability Unit.

The Land Use Capability Unit, in practice, is a management unit based on a conceptual division of the landscape. Identified and characterized by the individual factors of soil, rock type, slope classes, vegetation associations, and erosion type and severity, each factor serves as a key or link to vast quantities of supporting information in other geographic or non-geographic databases. The GIS provides the spatial vehicle for expression and extrapolation of this information.

Figure 1 shows the interrelationship between various geographic and non-geographic data sets held by DSIR Land Resources. This framework provides access to significantly more detailed information to support spatial interpretations. Spin-offs from data integration are improved levels of reliability, integrity and confidence in interpretation. The additional data sets also enhance the range of appli-cations to which the underlying geographic information can be put.

DSIR Land Resources is actively pursuing a number of areas for GIS applications. These include hazardous waste site selection and characterisation, environmental crisis management, hazardous waste corridors, wildlife habitat evaluation and management, risk assessment from pests, recreation planning, crop modelling and land evaluation, integrating GIS and decision support systems.

Presented below are three examples of GIS applications encompassing data integration, data modelling and interpretation which have improved the quality of policy development by using quantitative techniques to develop predictive models.

Disposal of Treated Effluent on Land, Auckland, New Zealand

A proposed on-land disposal of treated effluent was modelled according to several waste application rate scenarios and the capability of the land to sustain the applications, for the rural lands adjacent to Auckland City, New Zealand. Current impacts of the disposal of treated sewage into the harbour outfalls has created much discussion and dispute over the last ten to twenty years. Growing demand for urban expansion has placed pressure on the peri-urban fringe for development and has led to land use conflicts. Significant proportions of this land has high agricultural, horticultural and/or cultural value.

A review of the disposal options was undertaken, considering estuary, open ocean and land-based alternatives. The physical and environmental limitations to the disposal of treated effluent on land were investigated.

The New Zealand Land Resource Inventory and the non-geographic National Soils Database were linked using soil symbols. A correlation was established between soils with measured hydraulic character and soils with similar physical, chemical and mineralogical charact eristics, in a geographic context.

The ability of each soil unit to transmit and store water was characterized and a classification developed to enable the spatial expression of this information. This enabled the identification of areas with the potential for waste disposal.

The approach taken to determine the land capacity to sustain various levels of waste disposal and was based on the following assumptions:

- the soil is saturated;
- the soil is not artifically drained;
- lowlying land is not available (wet soils);
- shallow soils (steepland >25° slopes) are not available;
- no unusual rainfall events have occurred;
- no accumulation by lateral flow of ground water is occurring; and
- application rates were constant over a 24-hour period.

A broad-scale assessment, over the greater Auckland area, of the infiltration capacity for the soils was carried out. Using the New Zealand Land Resource Inventory database, all soil units were classified according to their ability to transmit and store water, and grouped according to a range of applications rates.

The model did not take into account the following factors:

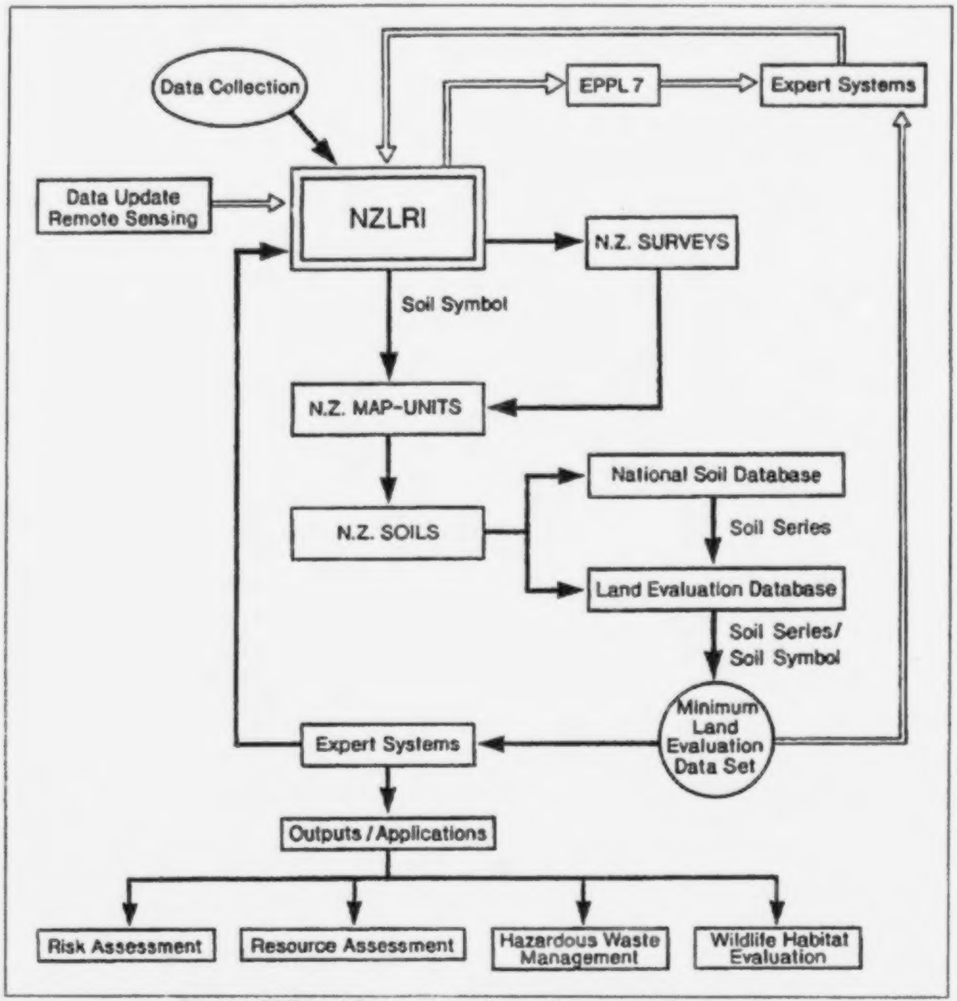
- method of application: high-intensity, short duration or low-intensity, long duration;

- crop selection and management, the type of land management system operative on the disposal sites;

- hydrology/hydrogeology, the effect of water tables and aquifers;

- effluent composition which impinges on toxicity, phosphate desorption and its consequential effect on freshwater and marine ecosystems; and

- changes of hydrology or increased flood susceptibility, slope or stream stability, groundwater contamination or possible land subsidence.


Data Collection
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National Soil Database
N.Z. SOILS
Soil Series
Land Evaluation Database
Soil Series/
Soil Symbol
Minimum
Land
Evaluation
Data Set
Expert Systems
Outputs / Applications
Risk Assessment
Resource Assessment
Hazardous Waste
Management
Wildlife Habitat
Evaluation

Figure 1. DSIR Land Resources databases: An Integrated Framework

As the basic assumptions used in the model take the worst case scenario of maximum soil wetness, some consideration needs to be given to the ability of the soil to handle higher weekly application rates when the soil is significantly drier.

Without the use of GIS and related databases, the assessment of land properties in a spatial context would have been impossible. The real advantage gained by using GIS was being able to assess several operational scenarios. Using a GIS database which has been developed around conceptual land management units also provides considerable advantages over a thematic database when trying to reconcile the spatial distribution of classified land.

The results of the study have provided a useful basis for the identification of potential sites capable of sustaining effluent application. The approach taken also emphasized the need for site-specific modelling to be carried out, taking a three dimensional view of the problem. Current develop-ments have extended this work to consider a more sophisticated three-dimensional model.

Rabbit Management in Central Otago, New Zealand

The introduction of the European rabbit (*Oryctolagus cuniculus* (L.)) into New Zealand was, by any standards, an ecological and economic disaster. In the semi-arid intermontane basins of the South Island, and Central Otago in particular, infestations of rabbits have depleted vegetation, induced soil erosion (Mather, 1984), reduced pastoral production (Thomsom, 1922; Munro and Wright, 1933; Wodzicki, 1950; Warner, 1956) and financially burdened land occupiers and taxpayers (Kerr et al., 1983).

A land systems approach for rabbit habitat modelling was developed by staff of the New Zealand Mountain Lands Institute and the Ministry of Agriculture and Fisheries (Kerr and Ross, 1990) as a basis for future rabbit managament policy.

Two applications of immediate practical significance for soundly-based classification of land for rabbit proneness were identified:

- as a land-taxing classification for financing rabbit management; and
- as a means of identifying lands where protection of land from the effects of infestation by rabbits may signal an alteration of existing land use.

Internationally, relating the distribution and density of wildlife species to land systems is widely used as a basis for establishing policies for wildlife management (Edwards et al., 1979; Rogers and Myers, 1978; Slough and Sadlier, 1977).

Method

Rabbit population numbers recorded along transects over a period of time were overlaid with land resource character-istics and statistically analysed to determine a quantitative land system rabbit proneness index. To ensure a satisfactory level of confidence in the data, only sites with five or more records were considered.

A generalized model was then applied to produce a rabbit proneness map for the greater Central Otago area of the South Island, New Zealand, using the New Zealand Land Resource Inventory (NZLRI).

The statistical analyses revealed a strong relationship between rabbit population numbers and soil type, vegetative cover and surface rock outcrops. The soils which occur in a lowland to montane, semi-arid to sub-humid environment provide warm and dry conditions, substrates suitable for burrowing, a low and frequently open vegetative cover, and shelter in the form of rocks and shrubs which are favourable to rabbits (Lynn and Hewitt, 1990).

Soil units were related to the recorded rabbit population information and the environmental conditions applying to those soils which naturally regulate rabbit populations were noted. This first level of classification was adjusted in the presence of improved pasture, crop or forest cover.

The classification described above is, as far as possible, an objective assessment of the propensity of various classes of land to sustain different though naturally fluctuating rabbit populations.

Each of the soil units for which there is no recorded rabbit population data were classified according to the degree to which each soil unit is considered to reflect those character-istics which naturally regulate rabbit numbers. Factors such as soil erosion, pres ence or absence of surface rocks or scrub, climate, and parent material were all gauged to be sufficiently differentiated in the hierarchy of soil survey information which provided the framework for classification used.

Results

An objective method of classification of land for rabbit proneness is of immediate significance because national and regional policies for the management of the rabbit pest are currently subject to review.

Foremost is the identification of extremely and highly prone land which henceforth will be subject to compre-hensive integrated rabbit and land management plans. These are aimed at ensuring conservation of land resources, coordination of rabbit control and land management, and the use of best available rabbit control methods.

Secondly, regional agencies responsible for pest control will, of necessity, be required to adopt soundly based classifications for the purpose of taxing land occupiers for the costs of rabbit control.

Both of these requirements mean that any classification for rabbit proneness will need to be accurate and equitable. Moreover, the classification must, in event of an appeal to the courts, be able to withstand close scrutiny by the judiciary.

The land systems approach provides a framework to assist with planning aspects of the rabbit and land management-related monitoring programme, including the regional distribution of monitoring effort and the transfer of information and results from the monitoring sites to the wider management area. In the derivation of the classification, less than ideal information was required to be used in some instances. The classification of rabbit proneness at this stage relies heavily on interpretation of the physical and other characteristics of the land resource information currently available.

GIS technology provided the vehicle for the integration of resource databases and the enhanced ability to develop more sophisticated quantitative models. This study provides the conceptual foundation for further habitat modelling using GIS tools. It will ultimately provide an informed basis for the development of national rabbit control and land management policies.

Integrating Land Evaluation and GIS

Different kinds of land are unequally suited to various uses. Common differences between land areas are their physical attributes, such as soil characteristics, climate, terrain and water resources. These are the subject of natural resource inventories such as soil surveys. Lands also differ because of current or past land use and the social and economic context within which they are used.

The primary aim of integrating land evaluation techniques with GIS is to present natural resource information, from a wide variety of sources, in a form that is directly useful to agriculturalists and land use planners. The work is intended for application to many areas such as matching crop requirements with land characteristics, or defining prime horticultural land for protection or other zoning.

The computerized land evaluation system is framework within which models may be constructed (Rossiter, 1990). It is a shell which provides a reasoning mechanism which allows expert systems to be built to evaluate land, by map units, from on-farm to regional scales. The system has several components; a knowledge base describing proposed land uses both in physical and economic terms; a database describing the land areas being evaluated; and an inference mechanism to relate these two, thereby computing the physical and economic suitability of a set of map units for a set of proposed land uses.

Each evaluation consists of a set of land utilization types (LUT), or proposed land uses, and a set of land map units (LMU), or land areas being considered. The map units are the same in both the land evaluation system and the GIS so the results from an evaluation may be transferred directly to the GIS database (Figure 2). Each map unit is evaluated for its suitability for each land utilization type, resulting in a combined physical and economic suitability matrix (Figure 3). Typical model outputs include physical suitability, gross margin, net return, costs and yield.

A pilot study was undertaken in Canterbury, South Island, to assess the utility of linking ALES and a GIS. Dryland wheat was selected as the land utilization type to be evaluated because a large amount of trial data was available to validate the model outputs. The evaluation area covered approximately 11 000km^2. A minimum data set of key land use requirements was collected for approximately 60 soil types mapped within the area. Decision trees were then constructed to relate land characteristics to land use requirements. Prices for inputs and outputs from the crop and interest rates were also collected.

Evaluation matrices were then computed and physical suitability, gross margin and expected yields determined. The ratings in the matrix were then compared against values determined by other methods such as yield models, expert opinion and farmer experience. Editing of the decision tree models was carried out where necessary and matrices recalculated until the validity of the models was deemed appropriate.

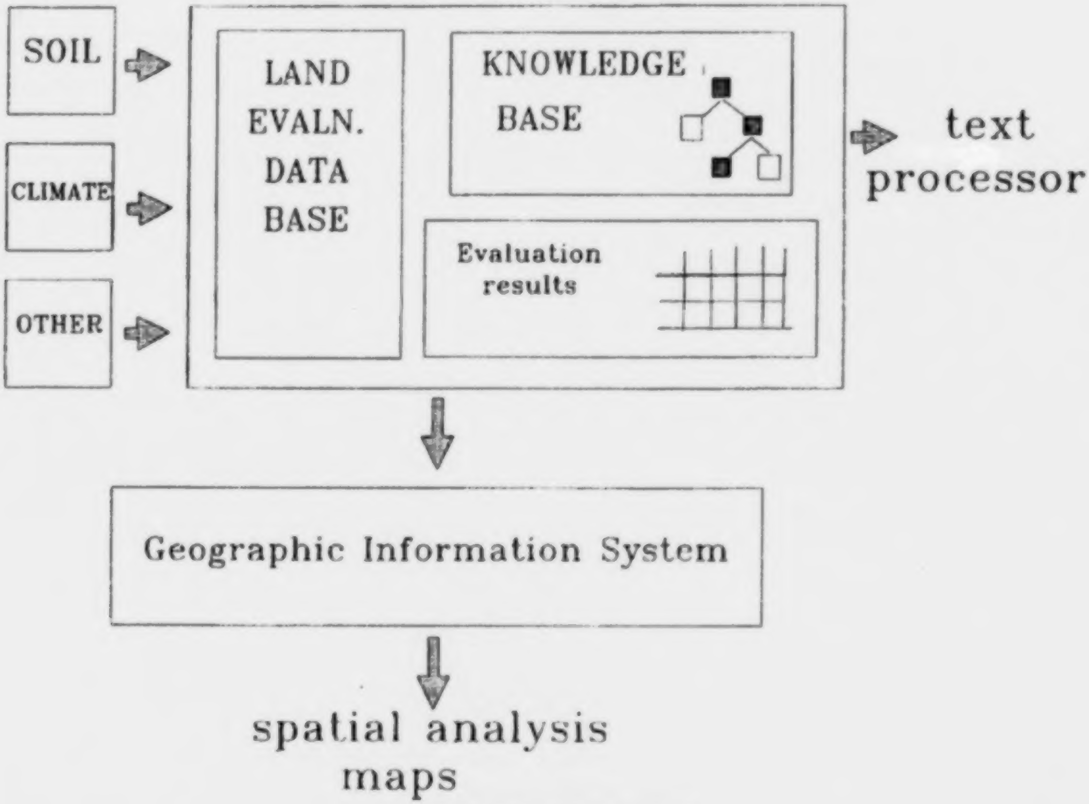

Figure 2 Land evaluation framework

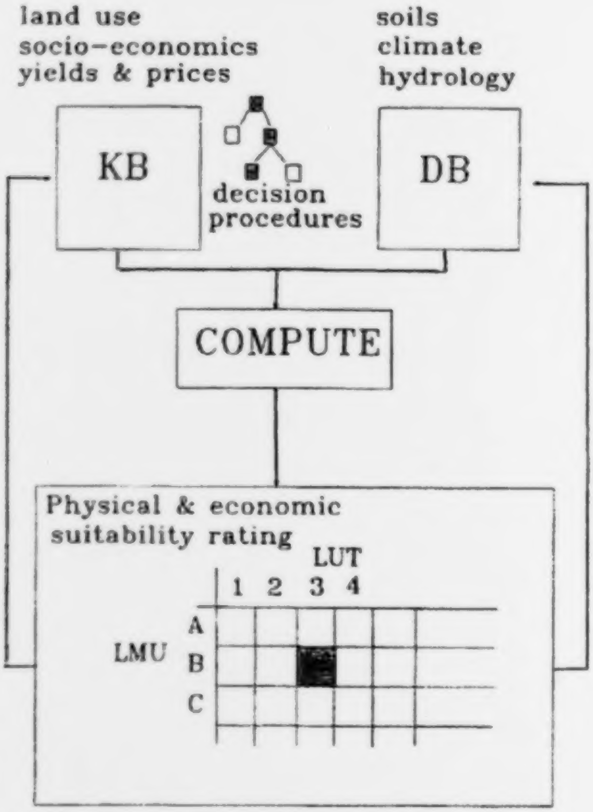

Figure 3 Land Evaluation System model

The evaluation results were then exported to a GIS where they could be displayed spatially. The ability of the GIS to overlay other relevant resource data layers proved invaluable when deciding on locations suitable for wheat production. These factors included availability of irrigation water, transport networks and proximity to infrastructural facilities such as grain storage and drying plants. These overlays provided another filter in the optimal allocation of LUTs within the study area.

Conclusion

The ability to link a land evaluation system to a GIS provides an effective tool to assist with regional land use planning. Output from evaluation matrices were overlaid with other data layers in the GIS to guide land use decisions. Future work will involve integrating simple, well-validated, quantitative models for yield prediction.

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Concurrent Session 12

Techniques: Remote Sensing and Video

The use of Satellite Imagery Combined with GIS to Manage Forests With Spruce Beetle Damage

Forest Landscape Management Opportunities Using a 3-D Image Analysis System

Video and Direct Digitizing of Aerial Photography for Forest Inventory

Multi-resource Inventories with Air and Space-borne Digital Remote Sensing, GIS and Video Imaging: Tomorrow's Vision, a Reality Today

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The Use of Satellite Imagery Combined with a Geographic Information System (GIS) to Manage Forests with Spruce Beetle Damage.

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Abstract

In the last five to eight years, large areas of central and southwestern Alaska have experienced the loss of thousands of acres of White Spruce (*Picea glausa*) due to infestations of the Spruce Bark Beetle (*Dendractonus rufipennis*). This problem has created both a major fire hazard and a potential economic opportunity. Alaskan native corporations with lands affected by the Spruce Beetle are actively investi-gating the feasibility of harvesting and processing this standing dead timber. Part of the investigation is an inventory of the affected areas. Because of the vast areas involved and their general inaccessibility, the use of satellite imagery was chosen as the most efficient means to conduct the inventory.

To date, a pilot area has been completed and is being evaluated by the participating agencies. The presentation will detail the process used to classify satellite imagery for the pilot area. Field data and existing color infrared aerial photography were used to derive the classification of the imagery. A combination of supervised and unsupervised classification algorthims were used. After classification, the resulting raster maps were ground-truthed to assess their accuracy. Imagery was classified into forest species and non-forest cover types. Percent crown closure, general size class, and general stand structure were classified for forest cover types. For White Spruce stands, percent beetle kill was also classified.

The raster data was converted into polygon data in the ARC/Info format and combined with an ownership layer of the same area. This makes possible a variety of analytical exercises useful in planning the most efficient and acceptable means of harvesting this timber .

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Forest Landscape Management Opportunities Using a 3-D Image Analysis System

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Abstract

The combined use of 3-D imagery, of both pseudo-natural images and classified images derived from satellite imagery, in a 3-D perspective form provides a strong information base for forestry management. Using historical data and filtering techniques, time series can be produced showing projected changes in the current scene and allowing inferences on future forest cutting programs. This joint project of the Ministry of Forests and EarthProbe Systems Ltd. attempts to demonstrate a dynamic approach to the visual impact assessment of forest harvesting.

Geographic Site

For the purposes of this development work we chose to examine an area in British Columbia encompassed by B.C. Provincial Map sheet 82G.031. This area we refer to as 'Moyie Lake'.

The area has been substantially logged since the mid 1970s and forestry now competes in this area, with a broad range of recreational users. Moyie Lake itself, on the eastern side of the image lies on a major through-way for both rail and automobile traffic travelling to and from the Crows Nest Pass through the Canadian Rockies. The lakes in the area attract a large number of boaters and fishermen. At the north end of the lake there is a substantial Provincial camp site and on the smaller Monroe and Hiawatha Lakes there are numerous private cottages and home sites. The naturally forested country to the west of Monroe Lake attracts hunters and hikers.

Less than 30% of the area contained within the map remains as old growth timber.

Project Resources

For the study we acquired 1:20 000 map sheets of the area. The first map sheet was generated from the B.C. Terrain Resources Information Management(TRIM) program and provided detailed contour information. From a digital version of the map sheet a gridded Digital Elevation Model (DEM) was extracted for the 3-D generation. A second map sheet, also at 1:20 000 scale, from the B.C. Ministry of Forests, provided recent forest cover information.

Two Landsat 7 band satellite image 'chips' were acquired covering the map area. The chips were small subsets of the overall Landsat scene, containing only 500 pixels per image line and with 350 total image lines. The first image provided current data (Summer 1990), the second image provided historical data from 1975. Both of the images were co-registered and geo-coded to match both the map projection and the gridded DEM.

The project was carried out using the EarthProbe One Image Analysis System. Along with the basic software, a special module was employed to generate and display the 3-D views. The software was running on a 80386/87 PC equipped with a 32-bit color display monitor.

The Natural Image

Utilizing bands 1,2,and 3 of the current image a 'natural' planimetric overview of the scene was produced by stretching and enhancing the raw data color values. Care was taken to try and ensure that the subtle differences between the cut areas of various ages was discernable and where necessary class masks were used to filter specific areas to make their tonal range unique.

The Classified Image

Bands 1,2,3,4,5, and 7 were used to develop a supervised classified image. Since our primary concern was the area within the cut-blocks, we specifically isolated regrowth within these areas and no attempt was made to classify the remaining forest in terms of species.

From this work, we were able to establish a series of image masks of areas where cutting was; 1) current (or less than five years old); 2) five years old; 3) ten years old; 4) twenty years old and 5) fifty years old. Class verification was obtained for the information from both the historical image and from the forest cover map.

The DEM Image

The DEM represents the surface elevation of the land and needs to be adjusted for average tree heights. In this image we arbitrarily used our classification masks to 'grow' each of the different tree/cut-block classes, according to the average age of growth. The current clear-cut areas were left at zero, as were roads, water bodies, etc., and the maximum height for old growth trees was arbitrarily set at 20 meters.

Green-Up Tables

A series of tables were set up showing the average tonal values in the natural image for every cut class. From this information and using the appropriate class masks, we were able to alter both the area hue as well as the stand heights. This manipulation was done by individually adjusting the RGB bands values for each band through the class mask according to our table of changes. Through this process we were able to; 1) retain the subtle ground detail information; 2) avoid the unnatural effects of 'hand painting'; 3) retain natural slope shading; and 4) leave the realistic residue of the logging operation still showing such as landing sites and access roads.

Establishing the View

From our examination of this area, we hypothesized that the most important overview of the visual effects of forest cutting could be obtained by generating a 3-D image from the east side of Moyie Lake looking west and a second view that would also be important should be taken from the north end of Moyie Lake looking southwest. In our first view, we selected an arbitrary view point from a few meters above the highway. This vantage point would put us marginally above the level of Monroe Lake. The second view point from the north east edge of the lake was located behind Hiawatha Lake.

The 3-D view generator which works in conjunction with the EarthProbe One Image Analysis System allows the user a very broad range of viewing parameters. The view point may be selected from within or outside of the image area and front and back cutoff planes are provided to minimize foreground interference or excessive background data.

From the viewing side, a window is arbitrarily variable for both X and Y axes, with both positive and negative controls. Through changes in the front window, X and Y vertical scaling relationships can be controlled. A Lambertian sun shade model allows us to introduce artificial variable intensity shading to the scene with full flexibility in the X,Y and Z directions for the sun location. Thus, shading and a sense of realism can be added to even a flat classified image.

The 3-D Images

3-D images were generated such that the view from the east of Moyie Lake was seen through a broad window which encompassed the entire length of the lake and with a view point set arbitrarily set far enough back that distortion as a result of a 'wide angle view' was minimized. The artificial sun was located to the south of the scene and two images were generated, one using the planimetric 'natural image' the second using the planimetric 'classified image'.

We used the 3-D natural images, along with the table for growth/green-up information that we had accumulated, to simulate the effects on the visual impact through a time series. We chose periods of 5, 10, and 15 years, at which point substantial visual green-up had been accomplished within the representation.

The tree heights 'grown' on the DEM provide clear demarcation of the roads as well as clear cuts. Tree heights correctly obscured much of the forward edges of cut areas and, along with the shading, adds to the natural overall impression.

Future View Projection

As a further part of our project, we then went on to investigate potential logging of a large area of old growth timber immediately adjacent to Moyie Lake.

An area of hypothetical cut was marked directly from the forest map sheets and digitized into the imagery. Arbitrarily, the area was cut into several segments, each one being given a separate color code on a new version of a classified image. The classified image with the potential cuts was viewed in a 3-D format, at which time we were able to quickly determine that certain of the sites would be entirely unacceptable for development based on visual impact. The objectional sites were then disregarded from our plan and the three remaining sites were artificially processed to show the effects of cutting one site each 5 years through a 15 year term. The effects of this cutting were accumulated onto the current images. Visual impact of these cuts were evaluated and it was determined that satisfactory minimal overall visual impact could be maintained throughout the cutting cycle.

Technology

The technology used for this project is neither new or complex; it is the application of simple image analysis which can be performed on a low-cost PC. 7 band satellite data can cost as little as 15 cents per square kilometer purchased an a full scene basis. The classified image information can be readily exchanged with GIS vector outlines. The software is simple to operate and provides broad project flexibility.

Conclusion

The 3-D image generated from the use of satellite and TRIM data provides an effective means for the visual display of forest harvesting. Through this approach year-round access to difficult terrain is simulated and views can be inexpensively generated that would be difficult to obtain by other means.

The capabilities of combining the pseudo-image with the classified key image is the important link in the visual interpretation. Regardless of how well the natural image was generated, we found when evaluating a 3-D view that it was often difficult to fully interpret the image in terms of relative cutting dates. In order to better understand and interpret these 3-D views, we found that a natural image alongside a classified image provided an ideal combination of keyed information. The natural image allows us to feel the visual impact; the classified image allows us to interpret the data.

Utilizing historical data with current information, we can provide a time series which allows foresters a realistic base from which to project the visual impact of regrowth patterns and green-up.

We believe this approach to landscape management provides significant advantages in the visual assessment of forest cutting plans that can be equally useful to foresters in both industry and the Ministry.

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Video Digitizing and Direct Digitizing of Aerial Photography for Forest Inventory

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Abstract

The following paper presents techniques currently being employed by McElhanney Geosurveys Ltd., and Northland Associates in the conversion of four hundred 1:12 500 scale digital map sheets.

The source data is comprised of conventional 1:50 000 National Topographic Series (NTS) maps, and current 1:12 500 (nominal) colour aerial photography. The computer hardware being used consists of three data collection 286 PCs, digitizing tables, plotter and printer. Additional hardware to be installed consists of video cameras, copy stands and video display boards for the PC. Computer software consists of McElhanney McMap data collection modules, ESRI, ARC/INFO processing and plotting modules, and as yet to be installed Nucor video imaging software.

The three data collection and edit workstations are operated on 2 eight-hour shifts per day. Processing, error detection, data conversion and file delivery, via RS232 cable, are all controlled by DOS Batch and ARC/INFO macros.

Background

The Province of Newfoundland and Labrador, Department of Forestry and Agriculture, has contracted for the delivery of approximately four hundred digital maps. This work requires the digitizing of approximately twenty-five 1:50 000 NTS maps and approximately ten thousand colour photographs.

The geographical area is approximately square, centered on Goose Bay, in the middle of Labrador. The terrain is generally hilly to mountainous with variations in relief of a few hundred metres in some areas.

The final digital file covers an area approximately 7 km by 8.75 km (61 square km) at a compilation scale of 1:12 500.

The average file encompasses some two hundred to three hundred forest polygons, each with some thirty characters of attribute data.

Methodology

Base Map Preparation

Twenty-five 1:50 000 National Topographic Series (NTS) are being table digitized. The original scribe sheets from the Department of Energy, Mines and Resources Canada (EMR) are used to prepare a photographic composite of the hydrography, linear features, and UTM grid. This assures the best possible definition and control for subsequent phases. Existing colour paper maps guide the coding of hydrographic and transportation features. The paper maps are also used to guide text name placement.

Once the digitizing of each map is complete they are segmented into sixteen portions based on the

Department of Forestry guidelines. These sixteen portions will contain the following required features:

- map limit (neat line);
- non-physical management unit boundary (if applicable);
- hydrographic features; and
- linear transportation features including transmission lines and roads.

These coverages do not yet constitute any single coverage requirement of the Department. However, final coverage extraction will be obtained at a later stage. Apart from the management unit boundary line and neat line, all other features are subject to modification as a result of the use of the 1:12 500 colour photography.

Forest Coverage

Certain features are extracted from each one of the sixteen 1:12 500 map sheets. These features fall into four groups:

- neat line;
- some hydrography;
- some linear transportation features; and
- management unit (other than physical features).

The combination of these features will permit forest type boundaries to be digitized to form closed polygons. The forest stands and updates are digitized directly from the photographs. In all cases, only a relatively small area surrounding the centre of the photograph is typed and digitized. The following procedures are being used:

Control: Each photograph is inspected for physical features that are also evident on the NTS basemap. Features such as points on shorelines, roads, etc., will be chosen and identified. Coordinates will be derived from the prior digitized maps for these points. Photographs covering areas having large differences in relief will be assigned more control than in flat areas.

Registration: Having numerous points on which to register each photograph means that the photograph can be registered in slightly different orientations.

Digitizing: The forest stand boundaries and updates to base features will be digitized in 'patches' per photograph. This digital patching is identical to the visual adjusting process that occurs when one uses reflecting projectors. The process of patching does not attempt to mean or average the relief displacement across the photograph; in fact, just the reverse occurs. Restricting the digitizing of new or update features to areas within each patch registration means that displacements due to relief in one area of the photograph does not affect other areas of the photograph. If an attempt is made to use a high order polynomial or least squares adjustment across the entire photograph utilizing a large number of registration points the results are worse than when patching.

Process Evaluation

Prior to implementing this patch digitizing, McElhanney undertook a trial to evaluate the methodology. We obtained a full set of photographs from the Department of Forestry in Corner Brook for one 1:12 5000 map sheet. Three separate tests were undertaken to determine the suitability of this method. First, the photography was stereo-digitized using a digitally encoded Wild B8 photogrammetric instrument. This map was used as a benchmark. Secondly, we used the approach described above to control, register and digitize each photograph. Thirdly, we used a reflecting projector to trace the boundaries. The three results were then compared. In areas of little or no relief displacement, there was virtually no difference between the three maps. As the relief displacement increased, the positions of forest boundaries diverged. The largest divergence approached one hundred metres when comparing the reflecting projector determined position to the B8 position. The table-digitized divergence was somewhat less, approximately eighty metres. It was also determined that the divergence was reduced with a larger number of patches per photograph. The converse was also shown to be true; an averaging with a large number of registration points across the photograph reduced the quality of the results.

Patch Digitizing

McElhanney is using our own data collection software to permit the patch digitizing of the photography. The sub-procedure within our digitizing software is known as digitized control.

The procedure is invoked in the following manner:

- Visually identify two or more, up to ten, locations which are common to a photograph and the already existing digital base;
- Digitize these chosen points in any order on the base. This can be done by screen cursor (mouse) or by table cursor;
- Signify the end of digitizing of base control;
- Digitize the same points on the photograph with the table cursor IN THE SAME ORDER;
- Signify end of photograph control;
- A Root Mean Square (RMS) error is computed and displayed. If this RMS is greater than acceptable points can be dropped or added until the solution is acceptable; and
- Once a suitable RMS value is obtained, digitize the forest polygon edges and update the hydrography as required.

The digitizing and feature update is always performed within the approximate polygon formed by the control chosen. The amount of relief displacement within one photograph determines the number of patches which will be registered and digitized. Areas of little or no relief require only one patch. We have determined that, on average, a maximum of four patches are required to accommodate the terrain in question.

Attribute Entry

There are two distinct kinds of attributes. The first refers to a point or centroid and line type, such as swamp symbol (centroid), the second refers to the inventory data.

All points, lines and, ultimately polygons are attributed with a three digit feature code. The forest stands also have the following inventory data:

- stand number;
- species type(s), site index, height class, age class and disturbance; and
- area.

All possible species compositions for the management unit have been entered into an ASCII file. When the operator chooses the feature code for a forest polygon, the cursor shape changes from a + to a scalable box. Secondly, a screen menu appears which prompts for all required inventory data except area. The operator input is compared to the valid lists to ensure as few key entry errors as possible. Once all data has been keyed, it appears in the scalable box, which can be moved around and scaled to permit proper text positioning. Each polygon will have text in one of two sizes, or if the polygon is too small, simply a stand identifier.

Video Digitizing

McElhanney, in conjunction with Nucor in Ottawa, have developed a method of improving both the registration process and the throughput of data collection. This process replaces both digitized control and the patch digitizing.

It relies on the use of a video camera and a video board with two separate graphic planes. The first plane is addressed by the video display software and second by the EGA vector display routines. This permits the operator to use the vector display plane in the same way as a standard colour graphics monitor. However, when the video camera is used a black and white image forms the background, as opposed to the standard black background.

This twinning of images permits the operator to focus an image of the photograph on the display and superimpose the base data. Using the zoom and pan capabilities of both the software and the camera, both images can manually be brought into coincidence. Once this state is achieved new and/or update information can be traced with a mouse or cursor directly from the screen.

The result of this visual coincidence is identical to that obtained with a reflecting projector image of a photograph onto a basemap. The zooming and panning equates to scaling and translating in x and y on the photograph. Tip and tilt and relief displacement are adjusted for by tilting the photograph on a pivot under the lens of the camera. We are now in the final stages of completing the linkage between our McElhanney software and the Nucor video modules. Our preliminary investigation indicates that the process is quicker than digitized control, and we expect it to be less fatiguing on the workstation operator.

Data Processing

Once all the data has been digitized for each map sheet, the files are converted to ARC/INFO coverage through the GENERATE format. Several hundred lines of ARC/INFO macros produce thematic coverages, error coverages, error reports and error plots. Error coverages are converted back to McElhanney McMap format and passed back to the operator. The entire process from McMap toARC/INFO to McMap is controlled by DOS BATCH processing which requires approximately one or two hours per map.

Once the quality control procedure produce no errors, the data is transmitted to the client. This process is again BATCH controlled and is initiated at night for the transmission of data over RS232 serial cables.

Resources

This database loading operation requires six graphic workstation operators working in two shifts. A project supervisor and a liaison person between the mapping staff and the forest stand typing staff complete the staff group.

Three 286 PCs with table digitizers, video cameras and a pen plotter are being used. One 386 PC is in continuous use, with a back-up 386 driving the plotter. At the moment only one copy of ARC/INFO is required; plans are in place to increase this to improve processing as additional work comes on stream.

Future Applications

We have learnt that under certain conditions it is possible to directly digitize aerial photography provided that:

- The end product does not require the high accuracy normally associated with photogrammetric solutions;
- The usable area of each photograph is restricted to that portion surrounding the principal point; and
- The relief displacement is such that the method of patch digitizing is appropriate.

McElhanney's experience with system installation and operator training on this project also points to the applicability of this concept in remote locations. We were able to mobilize, install and train, to the point of acceptable data production, in less than three months. In less than six months, each operator is currently producing a mapsheet a week. With the exception of our project supervisor no other staff member had any significant experience with microcomputers, much less graphic workstations and database development.

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Multi-resource Inventories with Air- and Spaceborne Digital Remote Sensing, GIS and Video Imaging: Tomorrow's Vision, a Reality Today

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Abstract

Public demand for reliable information about our natural resources will result in major changes in current forest inventory approaches. Systems which were designed to provide timber volume estimates for specific management units, at a given statistical confidence level, no longer meet the requirements of modern resource management, carried out under the scrutiny of an environmentally conscious and responsive public.

The new requirement of inventory systems is to provide descriptive statistics which are reliable in terms of individual stands or homogenous strata. Furthermore, these descriptive statistics must relate not only to timber, but to all the resources which the public insists must be considered in land use allocation and multi-resource management.

In this paper, the authors describe a statistical sampling system with the appropriate technology to deliver these multi-resource and site-specific information needs. In particular, the sampling system recommended is multi-phase sampling with partial replacement, using a combination of ground plots and airborne scanner data at high spatial resolution (0.5 m pixels) for 'photo sampling', and medium spatial resolution (5.0 m to 7.5 m pixels) for stratification. When fully calibrated, this system will have the potential to replace both large and medium scale analog aerial photographs. Geographic information systems will be the main data manager, manipulating information in three dimensions. Satellite image analysis systems, integrated with GIS, will provide monitoring capabilities through spaceborne imagery. Video imaging technology can also significantly enhance species identification and classification, as well as being used in combination with GIS to illustrate 'real life' conditions.

The new inventory system presented in this paper is based on a combination of a sampling system already well established by various agencies and the application of new technology. Some of these new techniques are already operational, while other components are ready to move out of their current R & D phase.

Introduction

In Canada, multi-resource inventories are based on a wide range of methods and techniques. Traditional field sampling with medium scale aerial photography is still a widely practised approach. This technology was developed with a strong focus on timber cruising. However, as the public demand for reliable information about both timber and non-timber resources becomes a major concern, the traditional inventory techniques may have serious constraints in delivering the required information. In particular, the current level of funding for resource inventories, which is generally less than $1 per hectare, falls short of resources sufficient for delivering reliable multi-resource information. Resource inventories, as currently practiced in Canada, are still maintaining a strong timber focus.

The general public, as well as special interest groups with major concerns for the environment, are presenting significant challenges to the existing resource inventory practices. They require that descriptive statistics be reliable in terms of individual stands or homogeneous strata, and that they cover not only timber but all the resources which the public insists must be considered in land use allocation and multi-resource management.

Proposed Multi-resource Inventory Model

Basic components of a generalized multi-resource inventory model include the following:

- planimetric and/or topographic (base) maps and data;
- cadastre (legal and administrative) maps and data;
- forest resource inventory maps and data;
- non-forest resource inventory maps and data; and
- socio-economic maps and data.

Processes within the above categories generate a multi-resource inventory data base. As soon as such data are compiled, there is a high probability that they will become out of date due to changes, such as depletions or growth. Hence, two new components are introduced next into the generalized model:

- projection over time with growth models; and
- updating with remote sensing.

These two processes yield a dynamic multi-resource inventory data base, which may either become the new updated data base or may be used in applications. Due to recent advances in technology, new land information products can be generated, such as color enhanced three-dimensional thematic maps featuring alternative land use options.

This new generalized resource inventory model is capable of providing the essential land information to a wide range of clients, including managers of forest resources, users of forest resources, service agencies, and environment protection and conservation groups.

Acquisition of Planimetric and/or Topographic Maps and Data

Current practices in Canada use maps and data which were collected over time, hence they contain a range of accuracy levels. As new planimetric and/or topographic maps become available, previously registered thematic forest inventory information may not fit the new base. Adjustments such as stretching, 'rubber sheeting' and other applicable techniques have been proven to retain high levels of error. It is recommended that as new and more accurate base maps become available, the multi-resource inventory be acquired from new aerial photography, which must then be registered to the new base map. In British Columbia, this process can be linked to the TRIM map production schedule.

Acquisition of Cadastral Maps and Data

The major challenge in this process is the integration of data sources which have different levels of accuracy. This is especially important in cases where the compiled boundaries may be subject to queries from the legal system. In addition, this process may obtain data from several agencies, using incompatible tolerance levels in terms of the accuracy and the amount of detail.

Once the necessary data is acquired, it must be kept current. Hence, cost effective and timely updating procedures must be an integral part of a multi-resource inventory model.

Acquisition of Forest Resource Inventory Theme and Data

This process is designed to utilize aerial photographs at scales of 1:15 000 and 1:10 000, together with temporary and permanent samples. The current funding levels of forest inventories are rarely sufficient to collect the number of samples required for the estimation of descriptive statistics on an individual stand or polygon basis. We recommend utilizing air photo samples for multiphase (double) sampling. The 70mm aerial photos at 1:500 or 1:1 000 scales used in British Columbia can provide the required information, which can be adjusted or 'corrected' with information obtained from ground samples. Both ground and photo samples may then be used for the development of multiple regression equations to provide volume estimates for each strata, assuming that the independent variables of the regressions can provide the necessary linkages to the stand descriptions,as used in the classification system.

Airborne scanner data with 0.5 m pixel resolution can provide a more efficient alternative to the current method of photo sampling. Measurements can be automated with the digital data, thus improving the current throughput problems. Airborne scanner data can facilitate some measure of automation in 'photo' interpretation.

The next major challenge is to transfer the boundaries of homogeneous strata to maps with the aid of photogrammetric techniques and GIS, including their corresponding descriptive statistics. Quality control is an important aspect of this process, and if implemented efficiently, can lead to major improvements in terms of cost effectiveness.

The appropriate sampling system recommended in this paper is multi-phase sampling with partial replacement (Loetsch and Haller, 1973; Cunia, 1974; and Hegyi, 1989).

Acquisition of Non-forest Resource Inventory Maps and Data

Multi-resource inventories also need to include information about the land base which provides descriptive statistics on non-timber resources. The leading components of this information base are fish and wildlife data, environmental sensitivity evaluation by aggregated strata, land use options, and consensus decisions on land allocation. The integration of information on non-timber resources with the forest resource inventory data base can be achieved through the use of GIS and image analysis systems. As the available information base in this area is currently incomplete, opportunities for linkages between the various data bases have not been fully explored. For the fish and wildlife data base, the forest resource inventory information can provide useful data on habitat. Opportunities exist to increase throughput and reduce the unit cost of producing land related information by making full use of the functional relationships between the various sources of data.

Acquisition of Socio-economic Maps and Data

Public concerns about forest management, land use options and allocations, and the negative effects of resource management will increase in the 1990s. Much is being said about the lack of reliable information for decisionmaking in environmental management, but little is being done about acquisition itself. Current data acquisition efforts are generally reactive, focusing on areas under land use conflict discussions, rather than being productive.

Important aspects of this process are information on environmental concerns about selected areas, criteria for conservation and their linkage to specific areas, and incorporation of the concerns of special interest groups representing hunting, fishing and tourism. Again, the current data base in this area is incomplete.

Acquisition of Informaiton on Growth

Information on the growth of the forest resource is extensive, but large differences in sample selection and mathematical modelling techniques produce significant inconsistencies between the existing growth projection models.

Major components of this process are empirical volume functions, growth equations and simulators, and time-series sample plot data. A key concern here is the calibration of growth models and their applicability to the resource inventory data base.

Applications of Remote Sensing Data

Remote sensing is used extensively in the acquisition of the forest resource theme data. The data currently used in that process is mainly airborne.

Opportunities exist for updating multi-resource inventories with spaceborne remote sensing imagery, such as the thematic mapper products of LANDSAT and SPOT satellites. This process is generally cost effective and accommodates large volumes of throughput. Quality control is emphasized as a major component of this process. Integration with GIS can also increase productivity in resource inventory sampling procedures.

Creation of New Applicaitons Products

Multi-resource inventory data, combined with digital elevation models and projected data bases and with GIS and image analysis software, can provide a range of new products in land related information. Such products as color enhanced thematic maps 'draped' over three-dimensional perspective views of selected watersheds can simulate the effects of various management practices. A particularly effective presentation technique combines these mathematical representations with an inset 'window' showing real video images of the same terrain.

Conclusion

The multi-resource inventory model described briefly in this paper is technologically feasible. However, the success of its implementation will depend on the availability of the financial resources and on the willingness to expand 'timber' inventories to include non-timber resource data.

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Concurrent Session 13

Engineering and Industrial Applications

Application of GIS to the Planning and Preliminary Design of the Vancouver Island Highway

Assessing Large-scale Slope Stability and Failure Within a GIS

Assessing the Effects of Aircraft Overflights: a Spatial Analysis Approach Based on a GIS

Application of Spatial Analysis to Fisheries Acoustics

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Application of GIS to the Planning and Preliminary Design of the Vancouver Island Highway

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Abstract

Crippen Consultants and Reid, Collins and Associates, Divisions of H.A. Simons Ltd., have completed the planning and preliminary design of a section of the Inland Island Highway between Qualicum Beach and Campbell River on Vancouver Island for the British Columbia Ministry of Transportation and Highways. The highway will consist of 127.8 km of 4 lane divided highway, 30+ km of other roads, 37 major stream structures, 9 interchange structures and 28 grade separations.

One of the tools used to support the planning process is GIS. The work involves the mapping and analysis of environmental constraints. Parameters of interest include fisheries, wildlife, forestry, water quality, hydrology, soils, vegetation, agriculture, land use and recreation. This paper will describe the procedures that were followed to develop the databases and applications, and discuss some of the lessons learned from the process.

Introduction

Increasing public awareness of environmentally sensitive projects and the liabilities associated with them has required land managers to fully justify management decisions and recommendations with proper backup information. Geographic information systems (GIS) can play a role in this process by organizing the information, and by providing some of the analytical tools required to support the decision-making process.

In November of 1989, the British Columbia Ministry of Transportation and Highways (MoTH) commissioned H.A. Simons Ltd., through its Crippen Consultants and Reid, Collins Divisions, to undertake the preliminary design of the new Vancouver Island Highway. In the Terms of Reference, the MoTH required the winning consultant to utilize GIS as part of the design process to address environmental design issues.

This paper will review how the implementation was achieved, will address the strengths and weaknesses of the implementation, and will examine some of the future potentials of GIS to this application.

The Highway Design Challenge

Crippen Consultants was responsible for preliminary design of 127.8 km of 4 lane divided freeway, with a design speed of 110 km/hr, extending from Highway 4A near Qualicum Beach to Menzies Bay north of Campbell River (Figure 1). Previous studies identified a study zone ranging from 3 km to over 9 km in width. MoTH divided the study into eight administrative zones for reporting and control.

The purpose of this study was to investigate and provide full reports on planning and traffic engineering, corridor selection, preliminary design and design packages. The Terms of Reference required submission of 34 reports, preparation and conducting of two public information meetings per section, and establishing and staffing of an Information Office within the study zone.

The study performed a corridor-style evaluation of routes including initial quantities and designs for an average of six options for each highway section and the initial evaluations of several alternative crossing sites. In addition, structural alternatives on 37 major stream crossings were also expected from the study.

Preliminary design included 37 major stream crossings, 9 interchange structures, 28 grade separations, including 8 designed for off-highway vehicles, and assessment of road improvements required to network roads connecting to the intersections.

The project team was comprised of 36 staff members on average, increasing at one point to 47 personnel.

Design data included hydraulics, highway engineering, structural engineering, and geotechnical engineering including test drilling, pit information, field surveys, aerial photography, and survey control using Global Positioning System (GPS) technology.

Reid, Collins was responsible for mapping and GIS resources for the planning component of the preliminary design. This included field data collation, map and report generation, and analysis for several disciplines. MoTH was interested in the impact of construction as well as the corridor and route alternatives. Disciplines of interest were:

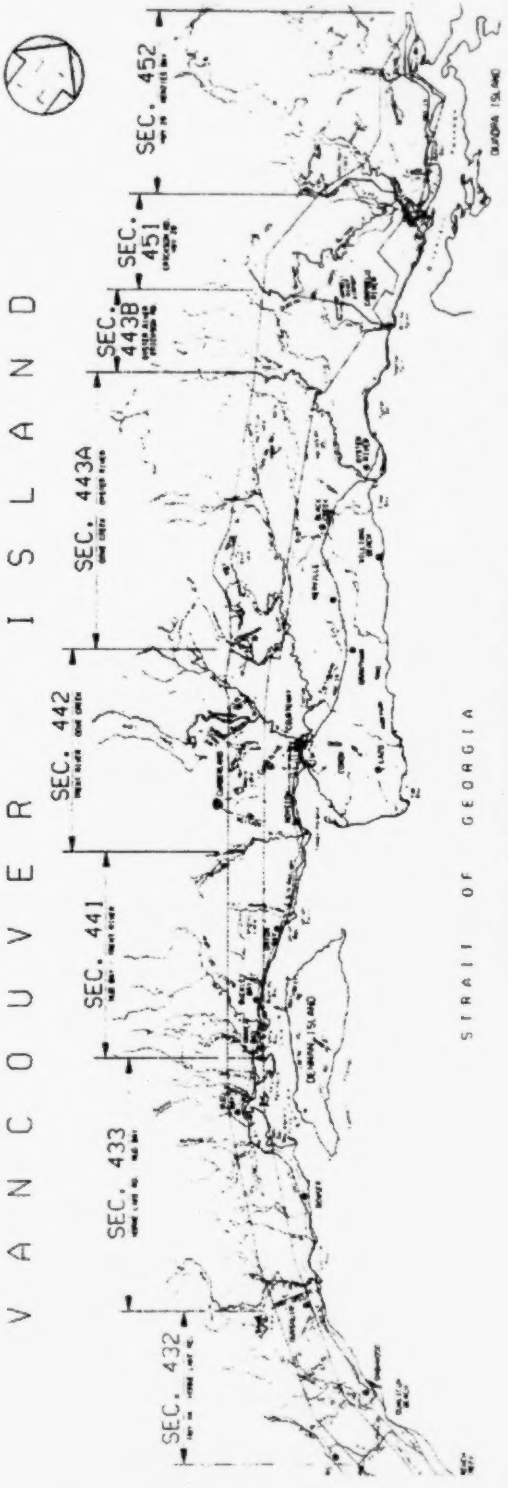


Figure 1 - Vancouver Island Highway Key Map

- fisheries,
- wildlife,
- forestry,
- water quality,
- hydrology,
- soils,
- vegetation,
- agriculture,
- land use,
- socio-community,
- recreation,
- traffic engineering,
- noise, and
- cadastral information.

Of these disciplines, the socio-community, traffic engineering and noise data were not implemented on the GIS. The cadastral information was added for use by Crippen.

The area of interest covered 68 1:5 000 maps. Mapping products were expected to be delivered in 1:2 000, 5 000, 10 000, and 20 000 scale formats. Graphics were to be of a quality suitable for presentation in public forums.

GIS Defined

For the purposes of this review, a GIS is defined as:

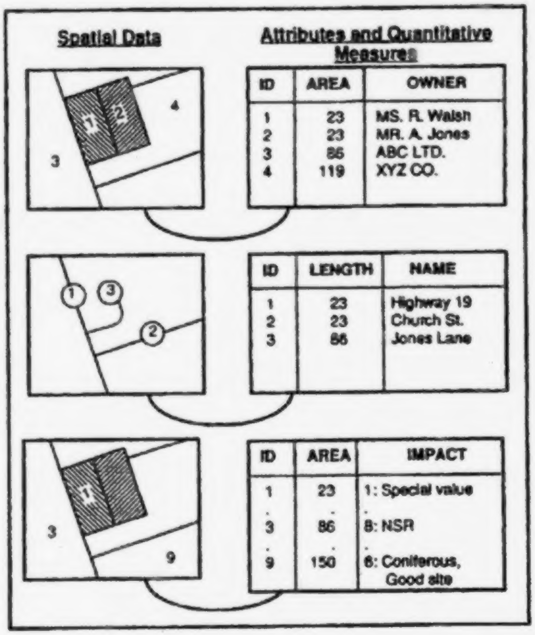
- a database of geo-referenced data as points, lines, and area boundaries;
- with associated feature codes;
- their topological relationships (connected to, adjacent to, shared with, inside);
- their quantifiable measures (length, perimeter, area, volume, centroid, proximity); and
- with associated attribute information.

In the most generic sense, a GIS can be understood to be any systematic approach, including a 'paper' system, for the organization of land-based data. A fully automated and integrated GIS would be a database containing all of the above locatable features, feature coding, topological relations, quantifiable measures, and all attribute information for features. Figure 2 shows examples of how the GIS was used to represent the information.

The hardware, software, network, and database are the foundation underlying the GIS. The user interacts with the aggregation of spatial data through the GIS and requires minimal understanding of the underlying technology (Figure 3). For highway design work, the user is not a single user but a team of specialists performing a variety of jobs such as data loading, applications development and GIS product generation.

Requirements Definition and Project Management

Data integration proved to be the most challenging part of this project. GIS has the ability to assist the user in integrating data sets from a variety of different sources.



ID	AREA	OWNER
1	23	MS. R. Walsh
2	23	MR. A. Jones
3	86	ABC LTD.
4	119	XYZ CO.

ID	LENGTH	NAME
1	23	Highway 19
2	23	Church St.
3	86	Jones Lane

ID	AREA	IMPACT
1	23	1: Special value
.	.	.
3	86	8: NSR
.	.	.
9	150	6: Coniferous, Good site

Figure 2 - GIS Concepts: Representing Spatial Data

However, this can only be successful if the project manager has taken the pains to define standards, procedures, and responsibilities in advance of the project startup, and enforces those standards through the project's life. While the project manager cannot have perfect prescience and must expect necessary revisions to these standards, every revision must be very carefully assessed. Arbitrary modifications to the data organization to address a single concern might ripple through the project to affect another group.

In addition to the conventional engineering skills, the project manager also has access to expertise in hardware, software, operating systems, networking, data exchange formats, computer languages and application development. The ability to access these skills quickly is critical to the timely delivery of results.

Hardware/Software Environment

H.A. Simons maintains a large computing facility in Vancouver to support its engineering projects. This facility maintains six Digital Equipment Corporation (DEC) VAX/VMS systems to provide file, computing and plot services. Local and Wide Area Network access between all of the company's buildings in the downtown area is provided via a DECnet fibre-optic and wire backbone. Processing power is provided at the engineer's desk using IBM Personal Computers and compatibles, VAXStation 3100s and Macintoshes.

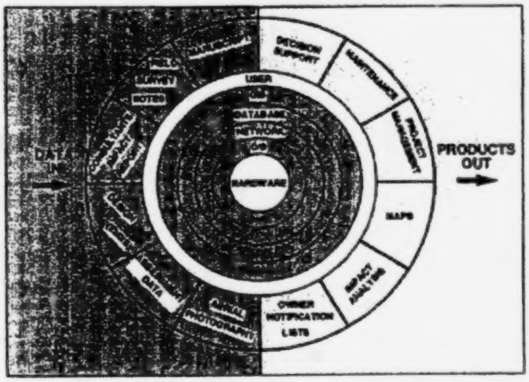

DATA IN
FIELD
SURVEY
NOTES
DATA
AERIAL
PHOTOGRAPHY
USER
DATABASE
NETWORK
GIS
HARDWARE
DECISION SUPPORT
MAINTENANCE
PROJECT MANAGEMENT
MAPS
IMPACT ANALYSIS
OWNER NOTIFICATION LISTS
PRODUCTS OUT

Figure 3 - GIS Concepts: Relationship Between Users, Technology and Data

The Island Highway Project utilized a variety of hardware platforms and software tools (Figure 4):

- Intergraph (Bentley) MicroStation software, running on PC-compatibles, for data capture, design work and graphic documentation;
- EMXS software, running on PC-compatibles, for highway design computations; and
- Environmental Systems Research Institute (ESRI) ARC/INFO GIS software, running on VAXStation 3100s, for map production and impact assessment.

Data exchange was effected through:

- SIF (Standard Interchange Format), an Intergraph flat file exchange format; and
- DXF (Drawing eXchange Format), an AutoDesk flat file exchange format.

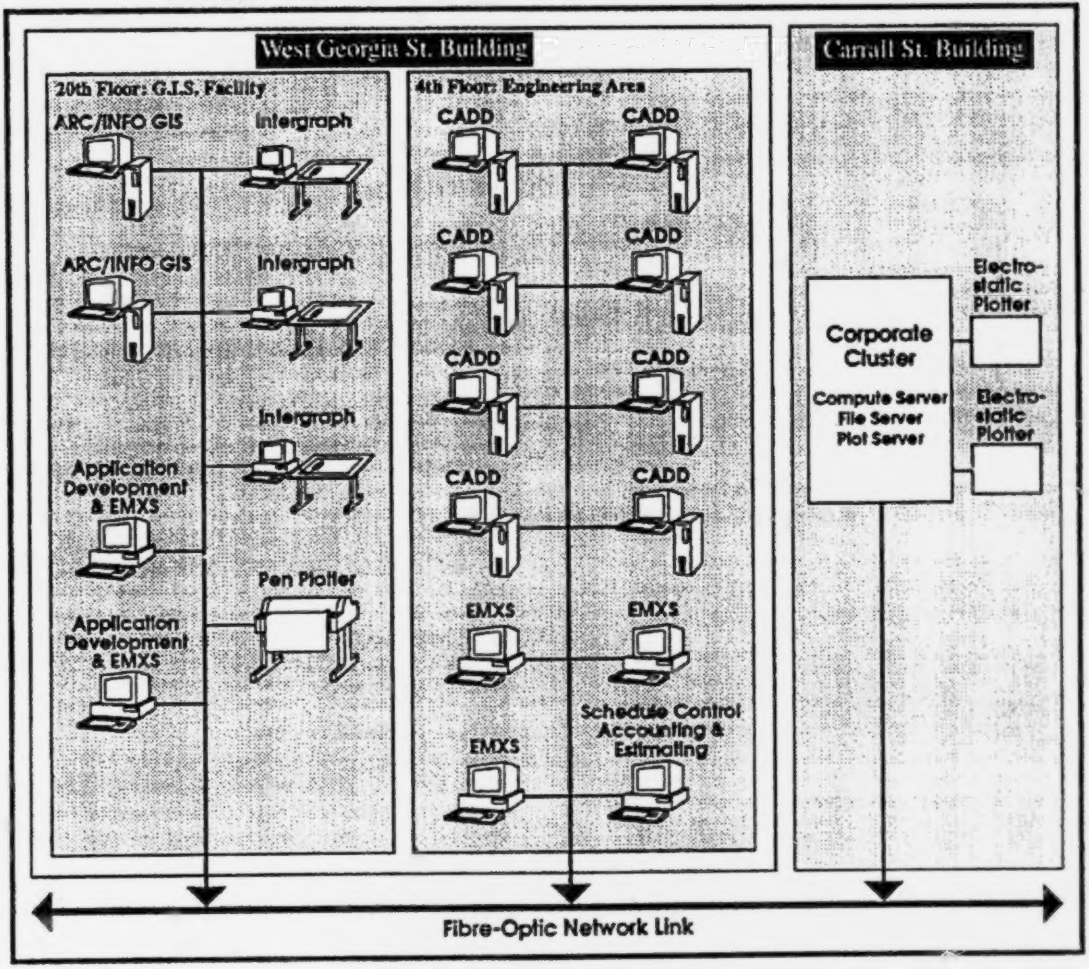
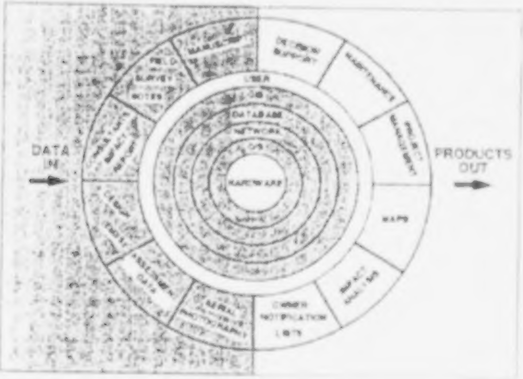

West Georgia St. Building
20th Floor: G.I.S. Facility
ARC/INFO GIS
Intergraph
ARC/INFO GIS
Intergraph
Intergraph
Application Development & EMXS
Pen Plotter
Application Development & EMXS
4th Floor: Engineering Area
CADD
CADD
CADD
CADD
CADD
CADD
CADD
CADD
EMXS
EMXS
EMXS
Schedule Control Accounting & Estimating
Carrall St. Building
Corporate Cluster
Compute Server
File Server
Plot Server
Electro-static Plotter
Electro-static Plotter
Fibre-Optic Network Link

Figure 4 - Project Computing Environment


DATA IN
PRODUCTS OUT
FIELD SURVEY NOTES
USER
DATABASE
NETWORK
HARDWARE
DECISION SUPPORT
PROJECT MANAGEMENT
MAPS
IMPACT ANALYSIS
OWNER NOTIFICATION LISTS
AERIAL PHOTOGRAPHY
ASSESSMENT DATA

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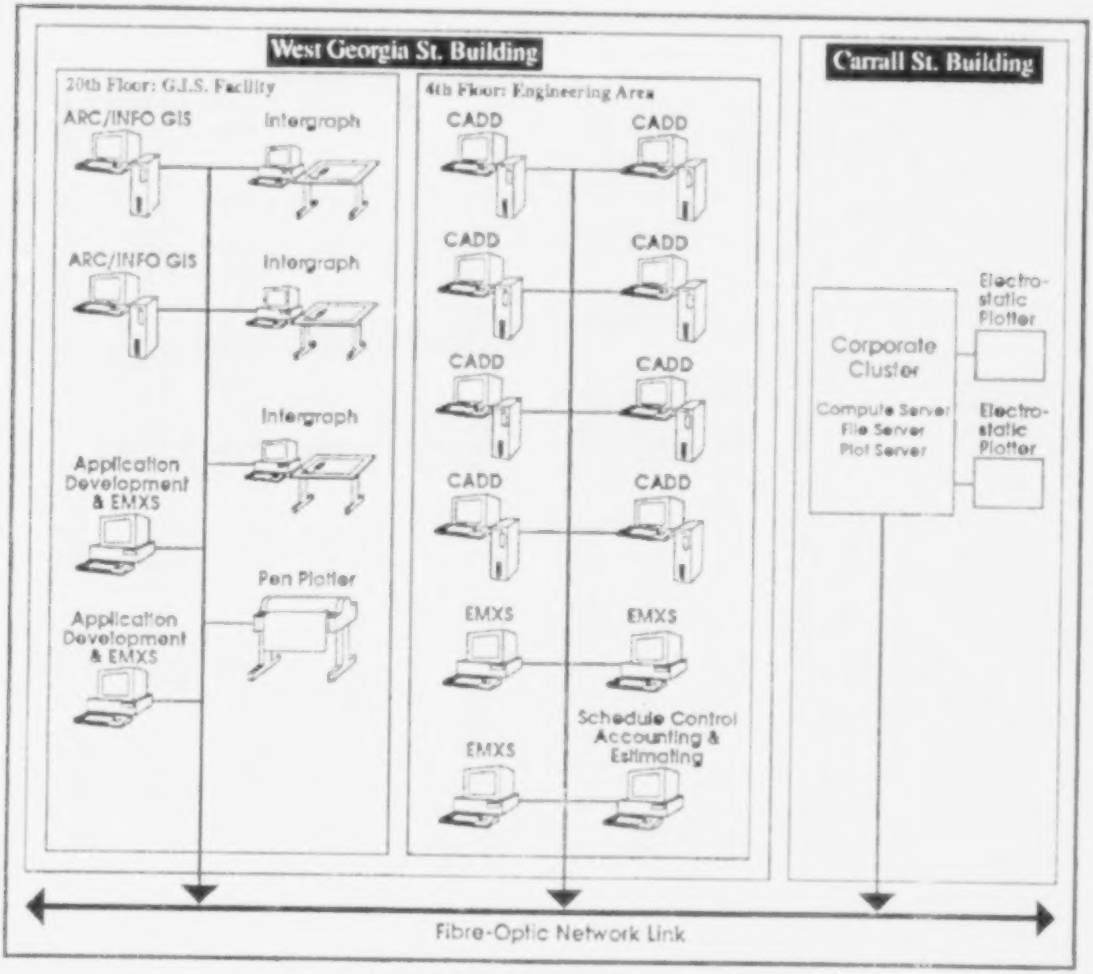
West Georgia St. Building
20th Floor: G.I.S. Facility
ARC/INFO GIS
Intergraph
ARC/INFO GIS
Intergraph
Intergraph
Application Development & EMXS
Pen Plotter
Application Development & EMXS
4th Floor: Engineering Area
CADD
CADD
CADD
CADD
CADD
CADD
CADD
CADD
EMXS
EMXS
EMXS
Schedule Control Accounting & Estimating
Carrall St. Building
Corporate Cluster
Compute Server
File Server
Plot Server
Electro-static Plotter
Electro-static Plotter
Fibre-Optic Network Link

Figure 4 - Project Computing Environment

Data Flow

As shown in Figure 5, data flow in this project required data handling methodologies for a variety of different data sources:

- photogrammetric data (interpreted aerial photography);
- topological field survey data;
- impact field survey data from a variety of consultants, highway design data; and
- owner notification data.

Base map data was maintained in the Universal Transverse Mercator (UTM) projection. The datum was North American Datum 1927 (NAD27). The scale of the base mapping was 1:5 000; neatlines were defined to British Columbia specifications for this series. A seamless map base was created using the ARC/INFO LIBRARY feature, thus allowing for production of maps at varying scales. The map levels (Intergraph) and coverages (ARC/INFO) were predefined by disciplinary content. Internal false origins were assigned for both systems.

Survey Control

Survey control was established for the selected corridor at the 1:2 000 scale using Global Positioning System (GPS) technology (Figure 6). Over a two week period, survey crews established 42 points to first order survey control standards (elevation was established to third order survey control standards). Since full satellite coverage was not yet available, the primary problem in the use of GPS was the limited time window available for taking measurements.

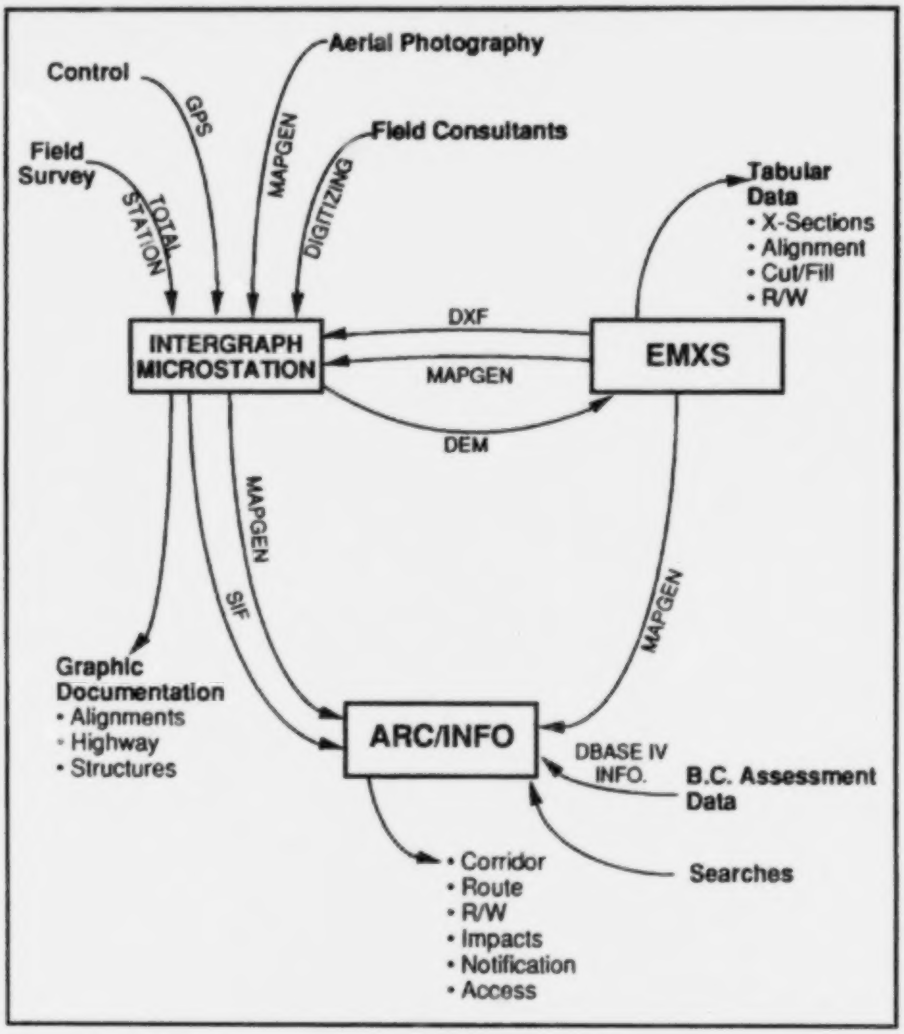
Aerial Photography
Control
GPS
MAPGEN
Field Consultants
Field Survey
TOTAL STATION
DIGITIZING
Tabular Data
• X-Sections
• Alignment
• Cut/Fill
• R/W
INTERGRAPH MICROSTATION
DXF
MAPGEN
EMXS
DEM
MAPGEN
SIF
MAPGEN
Graphic Documentation
• Alignments
• Highway
• Structures
ARC/INFO
DBASE IV INFO.
B.C. Assessment Data
Searches
• Corridor
• Route
• R/W
• Impacts
• Notification
• Access

Figure 5 - Project Data Flow

Survey control points were tagged and entered into the Intergraph system. The survey control file became a reference file for all other spatial files. These files could only be accessed in the multi-user environment in a read-only mode to ensure data integrity.

Photogrammetric Data

Large scale 1:2 000 maps with 2 m contours were produced from low-level aerial photography. The photos were acquired in early 1990 before the deciduous cover developed leaves. Improved vertical and horizontal control for a 500 m strip centred on the selected corridor was produced for detailed engineering analysis.

Photo-interpretation was performed on analytical stereoplotters. Specifications of the features to be identified, data density, output formats, etc., were provided to the subcontractor. MAPGEN, an H.A. Simons proprietary flat file format, was specified as the standard for data delivery.

MAPGEN is a feature-coded exchange format in which a feature is specified by a code and positional coordinates. Representational information and layer/level/coverage assignment is defined through an independent feature/attribute table. This mechanism separates feature identification from feature representation. End users of the data gain complete flexibility in which data is selected for use, what the representation of that data will be, and to what thematic layer the data is to be assigned. The same source data set can be used in the creation of different graphic products. MAPGEN was also used in other contexts in this project.

Topological Field Survey Data

New topological data was collected using Total Station technology wherever possible. The digitally encoded information was field corrected and translated to MAPGEN format. The MAPGEN format allowed direct entry, without translation, of the data into the master project map files.

Impact Field Survey Data

Environmental consultants were provided with a common set of 1:5 000 scale base maps for use in field work. Field notes indicating areas of concern were marked onto the base. Annotated base maps were returned to the H.A. Simons offices and digitally loaded by manual digitization procedures. A common eight point scale, across all disciplines, was to be assigned by the environmental consultants to areas within their terms of reference.

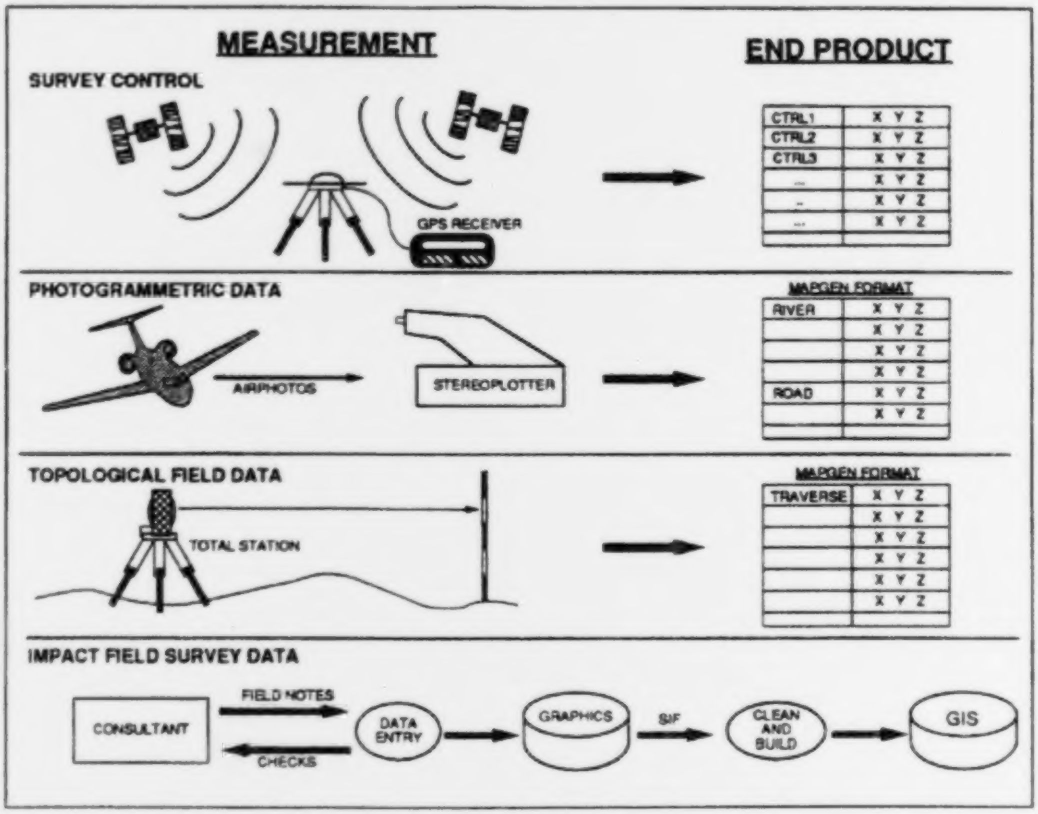
MEASUREMENT
END PRODUCT
SURVEY CONTROL
GPS RECEIVER
CTRL1 X Y Z
CTRL2 X Y Z
CTRL3 X Y Z
PHOTOGRAMMETRIC DATA
AIRPHOTOS
STEREOPLOTTER
MAPGEN FORMAT
RIVER X Y Z
ROAD X Y Z
TOPOLOGICAL FIELD DATA
TOTAL STATION
MAPGEN FORMAT
TRAVERSE X Y Z
IMPACT FIELD SURVEY DATA
CONSULTANT
FIELD NOTES
CHECKS
DATA ENTRY
GRAPHICS
SIF
CLEAN AND BUILD
GIS

Figure 6 - Detailed Project Data Flow

The amount of manual intervention required to enter the data correctly into the system, interpret the field notes, associate attributes with areas, and prepare the environmental disciplines for presentation made digital scanning an impractical choice for data loading on this project.

A cycle of digital loading, check map production, and consultant feedback was established for quality control. Initial topology checking for polygons was effected through the use of GRIDCON, a Pamap Graphics software package in the Intergraph environment. Since the GIS analysis was to be undertaken in the ESRI ARC/INFO environment, data was transferred in SIF format across the network CLEAN (solving overshoot, undershoot, and other connectivity problems) and BUILD (creating the database information to support the topological relations) cycles were run to finalize quality control on the topology and build the necessary topological relations.

Highway Design Data

Design data was entered into the EMXS highway design package from two sources: aerial photography data in MAPGEN format (contour information only), and field survey data also in MAPGEN format. Cross-sectional information was generated automatically from a Digital Elevation Model (DEM) created by EMXS. A 20 m coarse grid of points was used in order to reduce computation costs. The accuracy of the model was sufficient for preliminary design calculations.

EMXS provides for the creation of 'smart' cross-sectional templates which are created to sense height of fill and vary fill slopes accordingly, to sense different strata and to adjust the cut strata appropriately, and to handle other conditional situations such as following stratum lines. EMXS produced engineering computations such as volumes, mass haul diagrams, horizontal geometry, vertical geometry, right-of-way allowances, template points, and slope stake reports.

The cross-section diagrams were of sufficient quality for inclusion in the documentation package. However, the horizontal and vertical alignments suffered from two deficiencies: they were not of sufficient quality (annotations were incomplete or inadequate, line quality was poor, etc.) for inclusion in the documentation package, and they failed to show the alignments in context. For these reasons, the tabular data generated by EMXS was converted to MAPGEN format. Feature coded information (slope stakes, right-of-way line, ditches, pavement, centreline, point of intersections, point of tangents, station ticks and text, curve annotations) was transferred either to the CAD (Intergraph) or GIS (ARC/INFO) environment to produce graphic products. Figure 7 provides a sample of the graphical output generated.

Owner Notification Data

Notification lists of owners or tenure holders who would be affected by the proposed alignment were generated by combining British Columbia Assessment Authority assessment file records with corridor spatial locations recorded in the ARC/INFO GIS corridor coverage. Figure 8 shows the highway corridor overlaid on top of cadastral data. Table 1 provides an example of an owner notification list.

This portion of the project provided an interesting technical challenge: the Assessment Authority data was delivered in micro-computer database format with a legal description, but no georeferencing data (i.e., no spatial locator information). Since British Columbia has been surveyed using nine survey methods, the legal descriptions contain references to District Lots, Blocks, Lots, Parcels, Portions, Townships, Sections, Quarter Sections, etc.

In an attempt to automate the generation of the owner notification list, it was decided to develop a programme which would attempt to match legal descriptions as given in the database file, with textual descriptions as annotated on cadastral maps and survey plans. The programme generated a correct match hit rate of approximately 60%. Manual interpretation of the data raised the hit rate to 80%. The primary problems encountered were the irregular formatting of the Assessment Authority data and the irregular formatting of textual data on cadastral maps and survey plans. This irregularity caused significant difficulties in making matches.

It would be a valuable exercise for the Provincial Government to undertake the geo-referencing of British Columbia Assessment Authority data, and the production and maintenance of digitally encoded cross referenced cadastral maps for both Crown and privately held lands in British Columbia.

GIS Products

The end result of the GIS component of the project was a series of map products, impact analysis products and engineering computation products.

Maps

Colour maps were produced for preliminary corridors and corridors after initial public meetings. Figure 9 shows the preliminary corridors for Section 433 of the highway. The GIS allowed rapid turnaround of preliminary corridor documentation before and after internal meetings on potential routes.

Colour maps were also produced with impact ratings for the various environmental disciplines. Figures 10 and 11 show impact maps for fisheries and wildlife for one highway section.

Impact Analysis

An initial goal of the project was to develop a prototype impact analysis rating schema. The initial schema was to utilize a rating of 1-8 for low to high impact for each discipline. A formula for selecting aggregated low impact rated areas for initial corridor selection was to be implemented, highlighting those areas warranting engineering study for

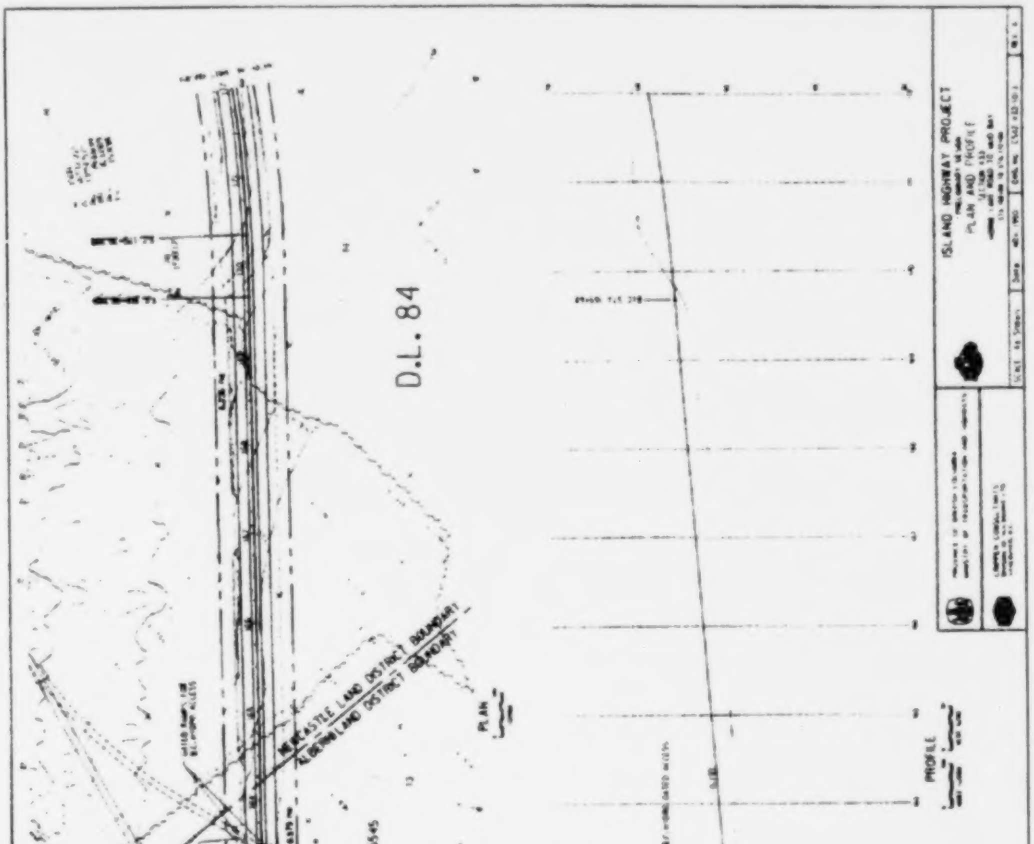
D.L. 84
Blk. 254
PLAN 35545
PLAN 35545
NEWCASTLE LAND DISTRICT BOUNDARY
ALBERNI LAND DISTRICT BOUNDARY
PLAN
PROFILE
DESIGN SPEED 110km/h
ISLAND HIGHWAY PROJECT
PLAN AND PROFILE

Figure 7 - Sample Design Drawing

Ownership Record of Required Property Within Section 443A

ID No.	Map No.	Owner	Area (ha)	Area by Owner	Property Type
7	2	ABC Properties Ltd	11.77		Rural Holdings
38	3	ABC Properties Ltd	3.72	15.49	Rural Holdings
144	1	DEF Properties Ltd.	12.08		Forest Land
177	1	DEF Properties Ltd.	0.28		Forest Land
178	1	DEF Properties Ltd.	11.47		Forest Land
22	2	DEF Properties Ltd.	0.23		Forest Land
37	2	DEF Properties Ltd.	1.46		Forest Land
22	3	DEF Properties Ltd.	2.67		Forest Land
92	4	DEF Properties Ltd.	0.33		Forest Land
115	4	DEF Properties Ltd.	0.59		Forest Land
120	4	DEF Properties Ltd.	10.03	39.14	Forest Land
45	3	Doe, John A.	23.20		Rural Holdings
58	3	Doe, John A.	14.79		Rural Holdings
110	4	Doe, John A.	0.66		Rural Holdings
187	4	Doe, John A.	25.73	64.38	Rural Holdings
64	1	Doe, John B., et al	2.03		Rural Holdings
82	1	Doe, John B., et al	1.73		Rural Holdings
100	1	Doe, John B., et al	1.74		Rural Holdings
117	1	Doe, John B., et al	1.75	7.25	Rural Holdings
26	3	Doe, Jane A.	6.32	6.32	Rural Holdings
54	4	Doe, John C.	5.58	5.58	Rural Holdings
134	1	GHI Forest Products Ltd.	0.09		Forest Land
6	1	GHI Forest Products Ltd.	5.32		Forest Land
24	1	GHI Forest Products Ltd.	9.82	15.23	Forest Land
41	2	JKL Logging Co. Ltd.	2.12		Forest Land
52	2	JKL Logging Co. Ltd.	1.00		Forest Land
59	2	JKL Logging Co. Ltd.	0.80		Forest Land
66	2	JKL Logging Co. Ltd.	3.17		Forest Land
80	2	JKL Logging Co. Ltd.	3.23		Forest Land
91	2	JKL Logging Co. Ltd.	6.68	17.00	Forest Land
23	2	Doe, John D.	15.48	15.48	Rural Holdings
135	1	MNO Forest Products Ltd.	3.55		Forest Land
17	2	MNO Forest Products Ltd.	0.18	3.73	Forest Land
82	1	Doe, Jane B.	5.68	5.68	Rural Holdings

TOTALS 195.28 195.28

Table 1 - Example of Owner Notification List

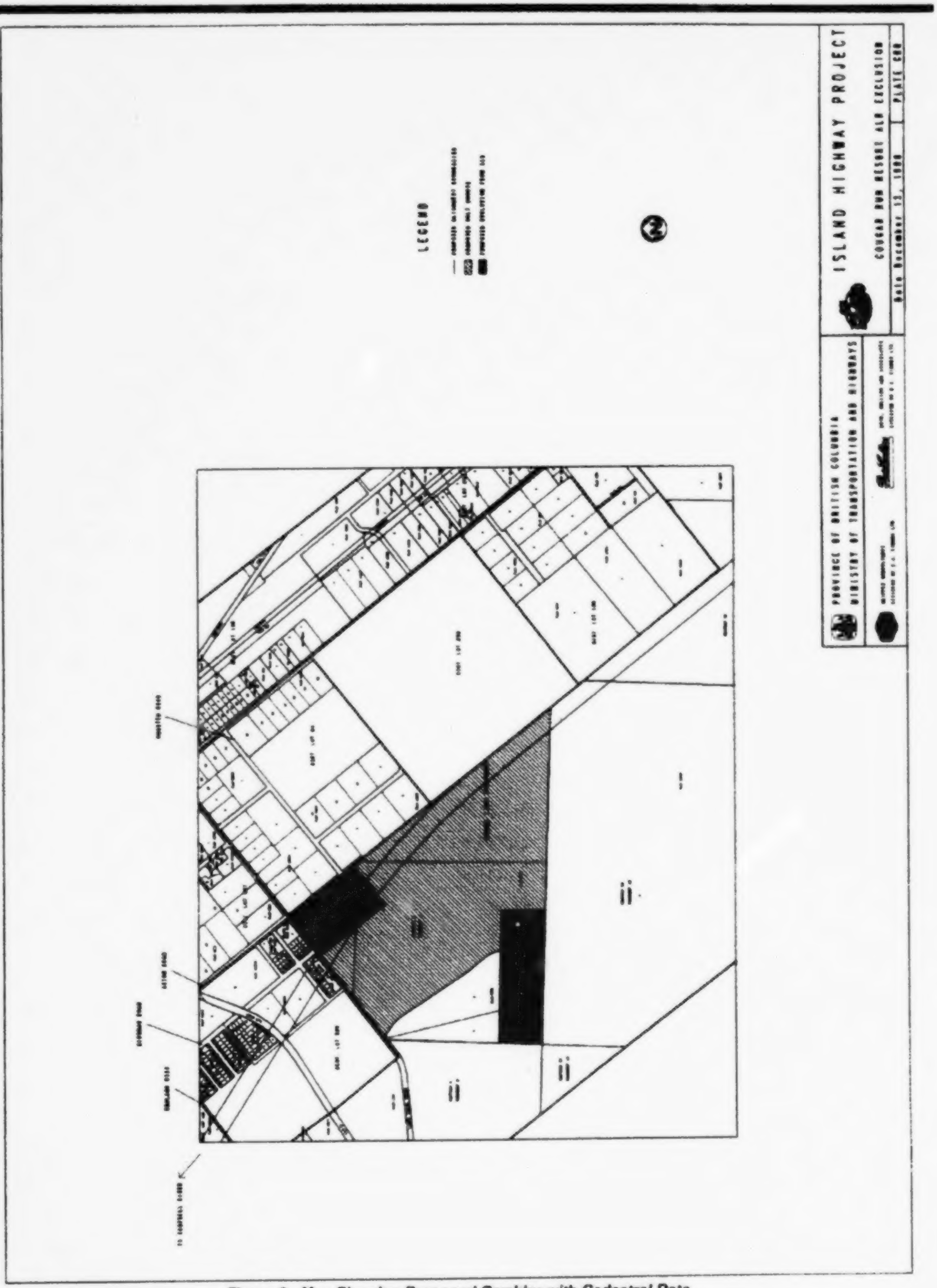
ISLAND HIGHWAY PROJECT
COUGAR RUN RESORT ALR EXCLUSION
PROVINCE OF BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND HIGHWAYS
LEGEND
ii
i

Figure 8 - Map Showing Proposed Corridor with Cadastral Data

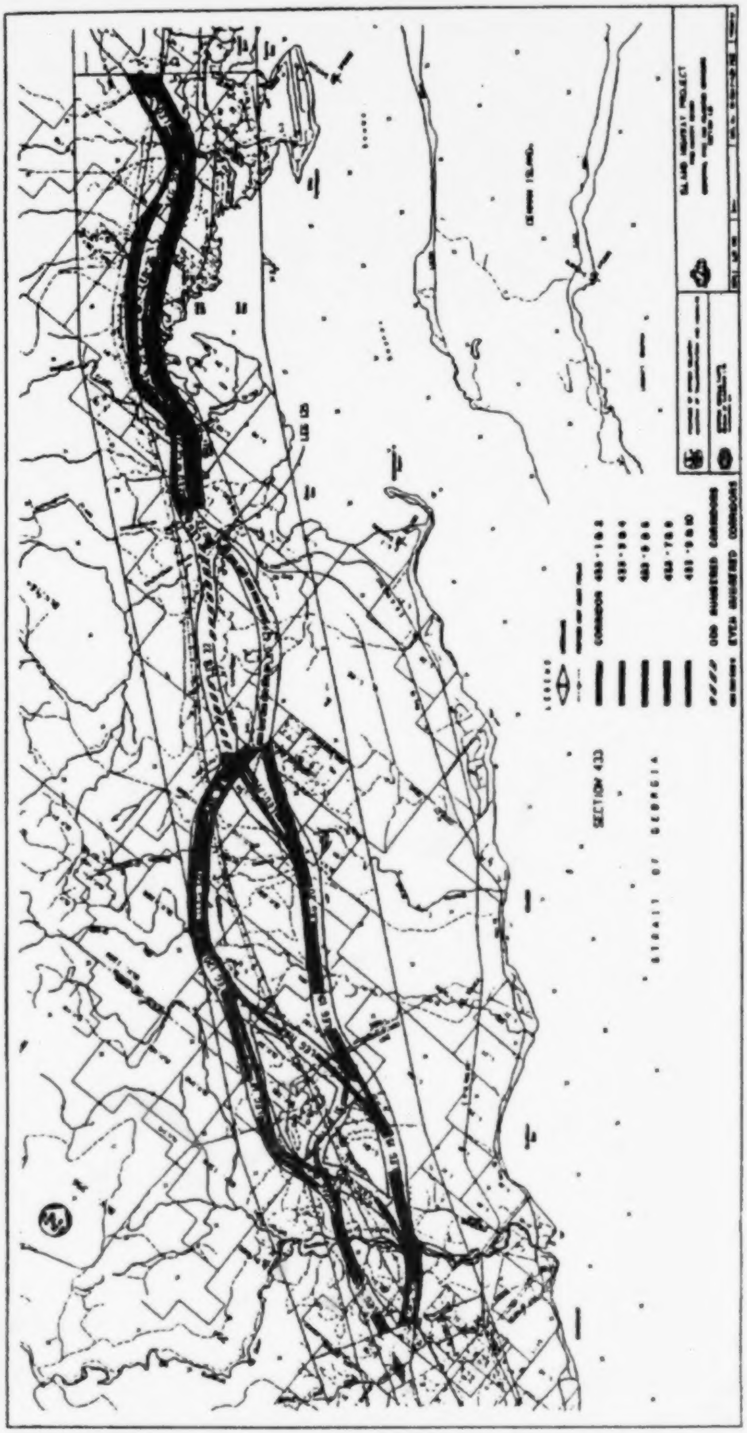
SECTION 433
STRAIT OF GEORGIA
LEGEND
ODD NUMBERED CORRIDORS
EVEN NUMBERED CORRIDORS

Figure 9 - Preliminary Highway Corridors for Section 433

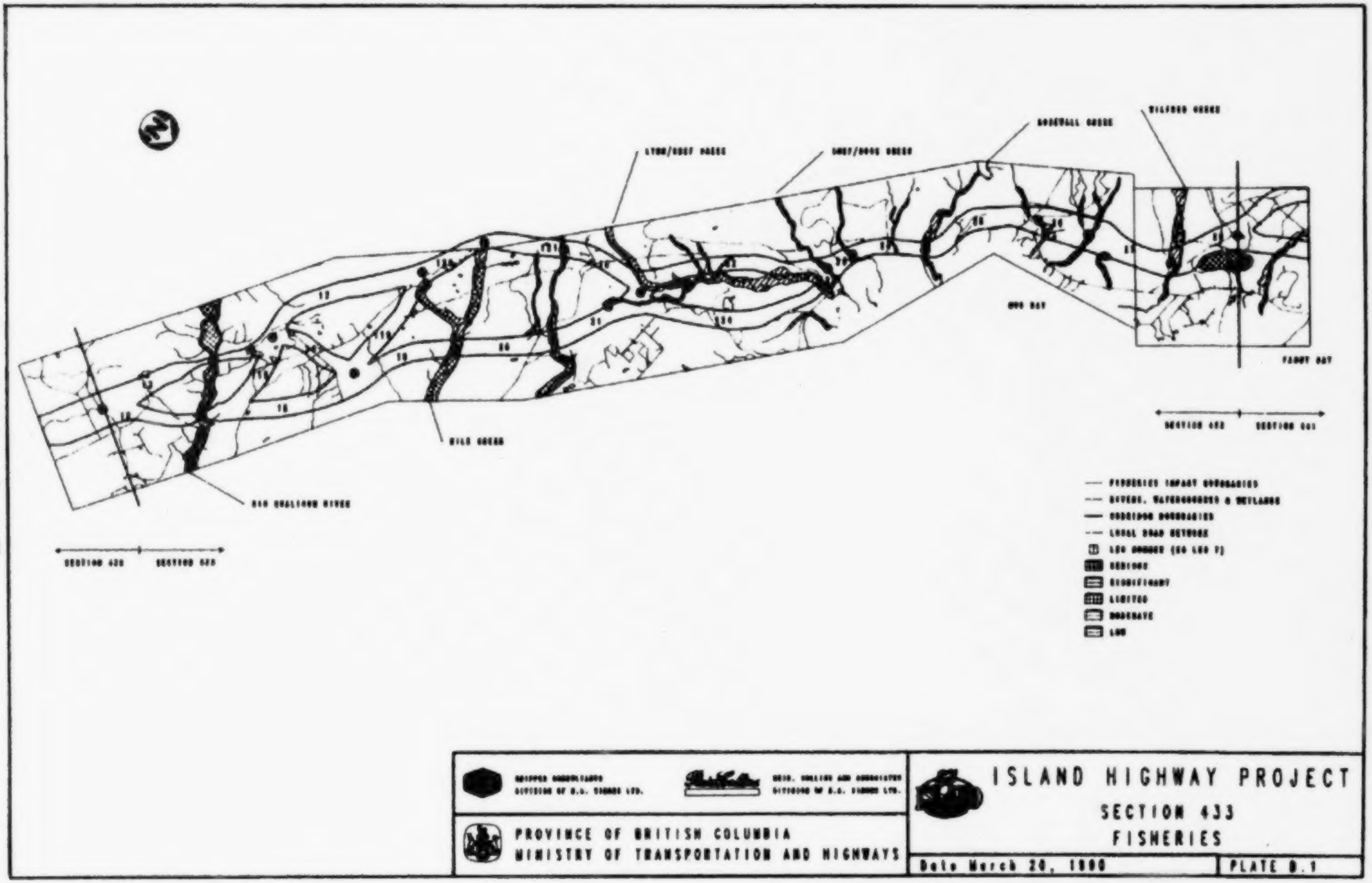
ISLAND HIGHWAY PROJECT
SECTION 433
FISHERIES
Date March 20,
PROVINCE OF BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND HIGHWAYS

Figure 10 - Fisheries Impact Map

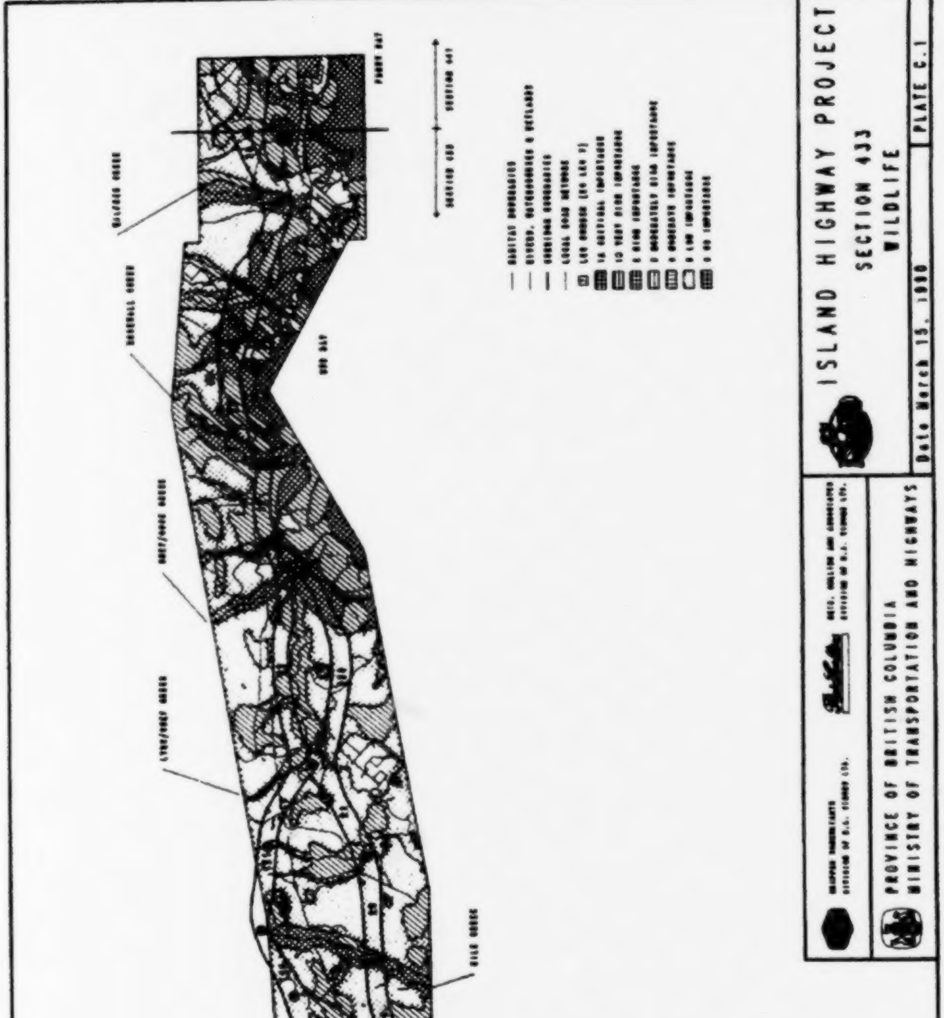
ISLAND HIGHWAY PROJECT
SECTION 433
WILDLIFE
Date March 15, 1990
PLATE C.1
PROVINCE OF BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND HIGHWAYS
HABITAT BOUNDARIES
RIVERS, WATERCOURSES & WETLANDS
CORRIDOR BOUNDARIES
LOCAL ROAD NETWORK
CRITICAL IMPORTANCE
VERY HIGH IMPORTANCE
HIGH IMPORTANCE
MODERATELY HIGH IMPORTANCE
MODERATE IMPORTANCE
LOW IMPORTANCE
NO IMPORTANCE

Figure 11 - Wildlife Impact Map

All forest cover types have been assigned a rating class/value class stratum. Rating Class 8 has been allocated zero value for timber. All merchantable forest cover types will be in Rating Class 8 on the assumption that all merchantable timber will be salvaged resulting in a zero loss or impact on timber.

Impact <1>
- Loss of Land with Special/Unique Value (eg. Permanent Sample Plot or Research Trial Plot)

Impact <2>
- Loss of Land with Special/Unique Value (eg. Demo Forest or Research Trial Plot)

Impact <3>
- Loss of Land with Coniferous, Good Site, 41-60 years (not yet merchantable)

Impact <4>
- Loss of Land with Coniferous, Med. Site, 41-60 years, or
- Loss of Land with Coniferous, Poor Site, 61-80 years

Impact <5>
- Loss of Land with Coniferous, Good Site, 21-40 years, or
- Loss of Land with Coniferous, Med. Site, 21-40 years, or
- Loss of Land with Coniferous, Poor Site, 41-60 years

Impact <6>
- Loss of Land with Coniferous, Good Site, 1-20 years, or
- Loss of Land with Coniferous, Med. Site, 1-20 years, or
- Loss of Land with Coniferous, Poor Site, 21-40 years

Impact <7>
- Loss of Land with Coniferous, Poor Site, 1-20 years, or
- Loss of Land with Deciduous, Immature, All Sites, 1-40 years

Impact <8>
- Loss of Land Classified NSR (not sufficiently re-stocked) or NCC (non-commercial cover), or Non-forest (within forested area)
- Loss of Land with Coniferous, Mature Merchantable
    - Good & Med. Sites, 61 + years
    - Poor Sites, 81 + years
- Loss of Land with Deciduous, Mature Merchantable
    - All Sites, 41 + years

Table 2 - Forest Impact Severity Rating Table

Impact	**Class and Area Losses by Corridor (Hectares)**									
Class	**433-1**	**433-2**	**433-3**	**433-4**	**433-5**	**433-6**	**433-7**	**433-8**	**433-9**	**433-10**
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0	37.6	79.2	29.5	71.1	28.5	70.1	28.5	70.1	20.4	62.0
3.0	31.4	16.3	25.3	10.2	31.5	16.4	46.8	31.7	35.7	20.6
4.0	102.1	81.9	63.4	43.2	98.1	77.9	98.7	78.5	57.5	37.3
5.0	82.0	89.8	102.2	110.0	60.5	68.3	67.0	74.8	81.5	89.3
6.0	84.7	92.3	122.7	130.3	81.5	89.1	77.5	85.1	115.9	123.5
7.0	7.6	4.7	7.9	5.0	16.9	14.0	11.2	8.3	12.5	9.6
8.0	262.4	239.0	272.4	249.0	286.4	263.0	293.8	270.4	309.5	286.1
Total Hectares Lost	607.8	603.2	623.4	618.8	603.4	598.8	623.5	618.9	633.0	628.4
Weighted Average Impact	6.0	5.8	6.2	6.0	6.2	6.0	6.1	5.9	6.4	6.2

Table 3 - Forest Impact Table

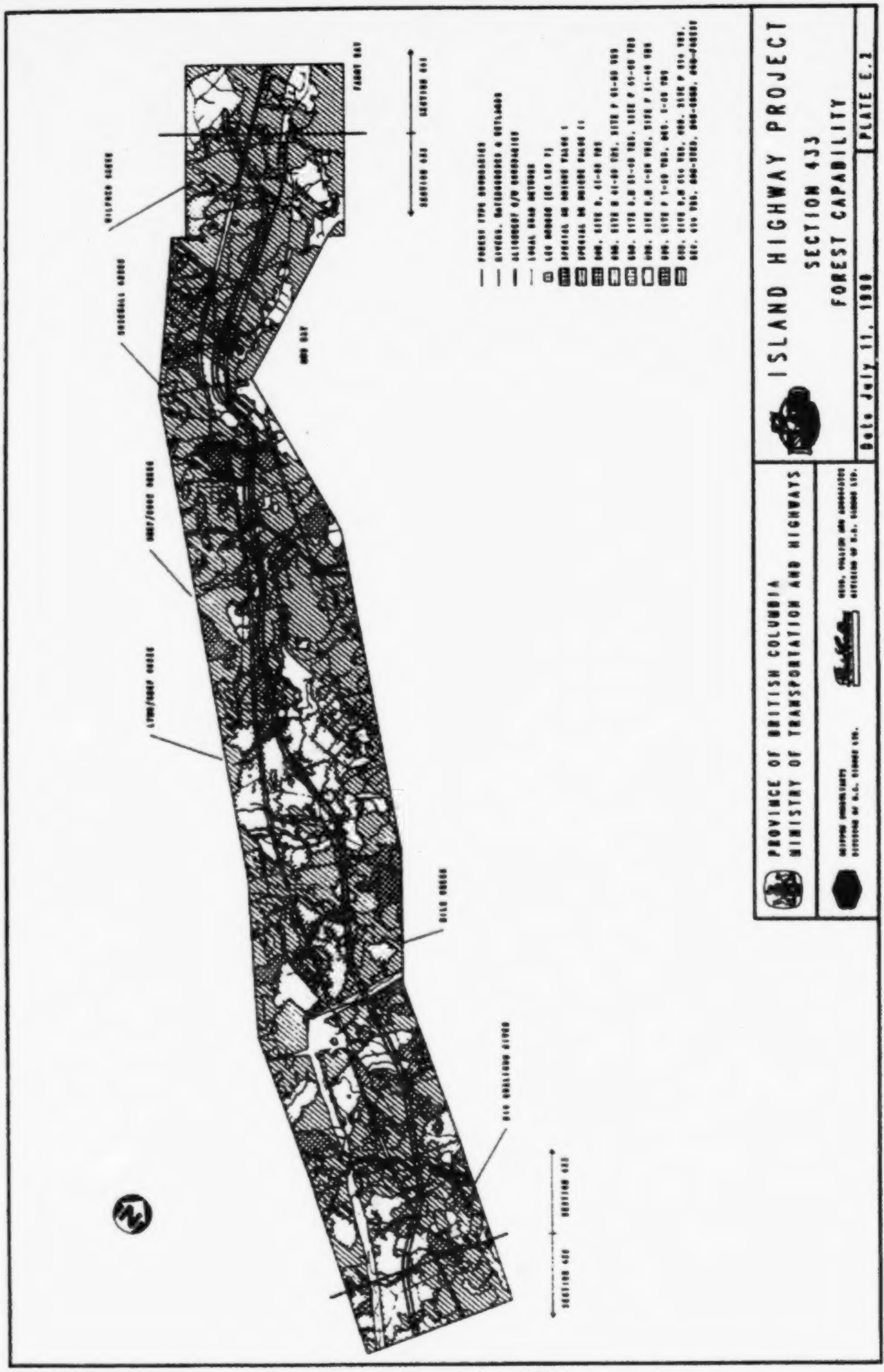
PROVINCE OF BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND HIGHWAYS
ISLAND HIGHWAY PROJECT
SECTION 433
FOREST CAPABILITY
Date July 11, 1990
PLATE E.2

Figure 12 - Forestry Impact Map

Qualitative Comparison: Corridors in Highway Section 433

Evaluating Discipline	Corridors in Section 433									
	433-1	433-2	433-3	433-4	433-5	433-6	433-7	433-8	433-9	433-10
1. Fisheries	P	A	P	A	P	G	P	G	P	A
2. Wildlife	G	G	G	G	G	G	G	G	A	A
3. Agriculture	A	A	A	A	A	A	A	A	A	A
4. Forestry	P	P	A	P	P	P	P	P	G	P
5. Vegetation	A	A	A	A	A	A	A	A	A	A
6. Water Resources	A	A	G	G	A	A	A	A	A	A
7. Soils	A	A	A	A	A	A	A	A	A	A
8. Hydrology	G	G	A	A	A	A	A	A	A	A
9. Noise	G	G	G	A	G	A	G	A	A	A
10. Land Use	G	A	G	A	A	A	A	A	A	A
11. Socio-Community	A	A	A	A	A	A	A	A	A	A
12. Engineering	G	G	G	G	A	A	A	A	G	A
13. Traffic & Functionality	G	G	G	G	G	G	G	G	G	G

Table 4 - Evaluation of Corridor Alternatives

engineering study for corridor suitability. Table 2 shows a forest impact severity rating table. Table 3 shows the use of this schema for highway section 433. Figure 12 shows a forest impact map.

This plan to use the rating schema foundered on several grounds:

- the impact schema was not uniformly suited to all disciplines;
- the schema was inconsistently applied by different consultants; and,
- the data was not collected and digitally loaded in adequate time to perform multi-scenario corridor analysis, particularly for initial corridor analysis.

The Environmental Project Coordinator was able to address the second of these concerns by creating a simpler schema: poor, acceptable, good. The schema corresponds to a scale of non-mitigatable impact, mitagatable impact, no environmental impact. This scale evaluated impact severity rather than a simple numerical value. Table 4 shows how the schema was used for highway section 433.

Futures

Impact Analysis

The Island Highway Project has demonstrated the use of GIS in impact assessment. However, there is still a need to construct multi-disciplinary impact tables which provide a coherent, consistent ranking scheme for all disciplines. Two requirements must be met; first, criteria for impact ratings must be defined in a rigorous, consistent and simple manner, and second, a weighting scheme should be added to allow the project manager to define weights for each discipline.

Table 5 - Weighted Impact Rating Table

Discipline	Rating	Weight
Fisheries	8	3
Wildlife	7	3
Noise	1	2
Agriculture	1	2
Socio-economic	7	2
Land use	1	2

The challenge here is to devise a method for calculating the weights. These weights would be a function of a variety of issues including how the disciplines interact, and how the topological and quantifiable measures in the GIS would contribute to the weighting. With the ratings in place, an automatically generated weighting scheme would then be developed to address the overall objectives for the project.

GIS as a Project Management Tool

Since the initial cost of generating the base data for the GIS is extremely high, the benefits accruing for that outlay may not be recoverable in the preliminary design phase of the project. However, benefits would probably outweigh the implementation costs if the GIS were permanently associated with the highway through its life cycle.

For example, some of the information required for the construction phase of the project is already in digital form and could be utilized. This data could be used to create access maps for contractors which highlight roads and potential access routes to construction sites. Now that the database is in place, the development of management applications would be much more straightforward.

Highway Maintenance

The MoTH could use the GIS to as a tool to address a variety of maintenance and environmental issues. Possible applications would include:

- environmental impact of snow removal techniques;
- modelling avalanche behaviour in high snow or steep slope areas;
- noise impacts upon growing communities in proximity to the highway;
- preliminary design of connector highways;
- history of pavement performance and scheduling of
- accident history and its statistical analysis.

Summary

As a relatively new technology ion highway design, GIS has demonstrated its power as a tool in support of corridor selection, environmental impact analysis, public information sessions, notificaiton requirements, and engineering design. The critical issue for successful implementation remains the availability of up-to-date digital data, and timely incorporaiton of new project data. Once these issues are resolved, GIS will become a useful tool for highway design project.

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Assessing Large Scale Slope Stability and Failure Within a Geographic Information System

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Abstract

A number of diverse methods exist to describe and understand slope stability and failure, ranging from general and simple 'assessment' methodologies to complex mathematical 'predictive' models. Given recent advances in affordable computational capabilities and the associated advent of increasingly sophisticated geographic information systems (GIS), the possibility of integrating slope stability analysis within GIS becomes feasible. A study has been undertaken to examine the possibilities of integrating known slope stability methodologies in a GIS environment. A number of factors have been identified to control feasibility of slope failure integration within GIS. These factors include scale of resolution (specifically at scales greater than 1:10 000), model specification, data complexity, and data availability. This paper identifies and summarizes different classes of slope stability and slope failure models, discussing issues of resolution, data complexity, and scale in relation to GIS.

Introduction

Failure to identify areas of potentially unstable forest terrain can have short-term and long-term direct and indirect monetary and environmental implications. Local impacts concern potential road collapse and property loss. Introduction of failure debris into local hydrologic systems adversely affects the water quality of rivers and lakes. Consequences of this include environmental impacts on fisheries and recreational opportunities, potential causes of flooding due to sediment deposit, and potential property losses. Loss of surficial soil mass implies accelerated erosion. This can increase regeneration cost after forest harvest, resulting in a potential delay or loss of future forest revenue.

The ability to effectively conduct routine analysis of a region's potential for slope failure and soil loss would benefit the definition of harvest plans and harvest options. Such analyses would also be a useful parameter to incorporate in the location of logging roads and other infrastructures.

Surficial soil structure is especially vulnerable to erosion during the years immediately after harvest. The ability to predict slope failure after harvest thus yields warnings to silviculture programs, allowing for the development of management strategies to concentrate re-growth efforts on areas of high failure probability.

A study was undertaken by Shasko (1989) to address the plausibility of predicting slope failure, and the transferral of this understanding to the realm of pre-harvest and post-harvest soil assessment. In the process, a number of strategies and methodologies for predicting slope failure were examined. It was recognized that the computational complexities and the sheer volumes of data involved in this type of analysis require efficient computational platforms to manage, manipulate, and display the data and results. Powerful computational platforms to undertake this type of analysis have existed for some time. However, management of the large and complex topological data required as input into the models has proven awkward on these computational systems. Also, the ability to visualize results has been lacking, and the man-machine interactive interface has been unfriendly to computer users. Routine slope failure assessment by practising foresters and resource managers using relatively sophisticated mathematical modelling has therefore been the exception rather than the norm. Geographical information systems (GIS) offer a computing environment capable of managing large volumes of topological data where the efficient and effective visualization of the results can be undertaken in a more user-friendly environment. This study focused on the feasibility of integrating slope failure prediction modelling within GIS.

Historically, early developments in GIS have concentrated on data inventory, topological overlay, and simple spatial queries. It is only in the last few years that efforts to integrate more advanced spatial analyses within GIS have occurred. Given the above, the importance of GIS to resource management, and the strong historical ties between GIS development and forestry management, incorporation of sophisticated slope stability models within GIS represents a logical progression. A goal in the GIS research agenda, therefore, should be to allow foresters to use GIS to assess a multitude of stability/failure parameters using different models to examine management scenarios whereby harvest plans and silviculture strategies can be augmented.

Slope Stability Models

Our understanding of slope stability and slope failure is significant, although not perfect. Models have been developed and tested. However, two major problems can be identified with their implementation. First, there now exists such an abundance of models that the practising forester is confronted with the challenge of identifying which model best represents prevailing conditions for a given management scenario. Second, a number of available models are extremely data-hungry, and supplying sufficient data to meet the model's requirements often becomes a non-trivial task.

The majority of models require detailed site specific data. Some of this data has to be collected in the field, yet other data can be derived from terrain models, existing inventory, and satellite imagery. Attempts, however, to derive input data from digital terrain models and existing digital inventory, must ensure resolution and scale compatibility. Moreover, applications at differing scales will involve varying data requirements, and since some of the models are scale-specific, model selection can be error-prone.

It should be obvious from the above that any integration of slope stability modelling within GIS requires a thorough examination of the nature and data requirements of the different models developed and tested over time. Towards this rationale, the following discussion introduces and examines a number of recognized stability models, placing emphases on computational complexities and data needs for inclusion in a GIS.

We should note that one approach that is commonly utilized to model potential slope failure within GIS is to use available digital terrain models to determine what land has a slope exceeding a potentially unstable threshold value of, say 30 degrees. This method of slope failure prediction is useful for small-scale analysis and executive overview. The following discussion concerns itself more with slope failure models that aim to assess failure potential for large-scale analyses where terrain models would not be solely utilized for the analysis.

Model Specifications

Forces acting on a given mass of inclined soil can be resolved into a number of components. Depending on whether rupture occurs along a planar or linear shearing surface or a curvilinear shearing surface, different components of force are present. Assessing the forces along a curvilinear surface is inherently more complex due to a rotational component rather than a simple linear displacement. Figure 1 illustrates the possible forces acting on a given curvilinear surface. For the linear case, one 'slice' with a constant slope angle and no rotational components is considered. Regardless of the shearing surface, however, five basic forces, defining the resisting and driving components acting against a given point along the shearing surface, can be resolved (Selby, 1982, O'Loughlin, 1974). They are as follows:

1) Normal stress, σ - forces downward and perpendicular to the failure plane.

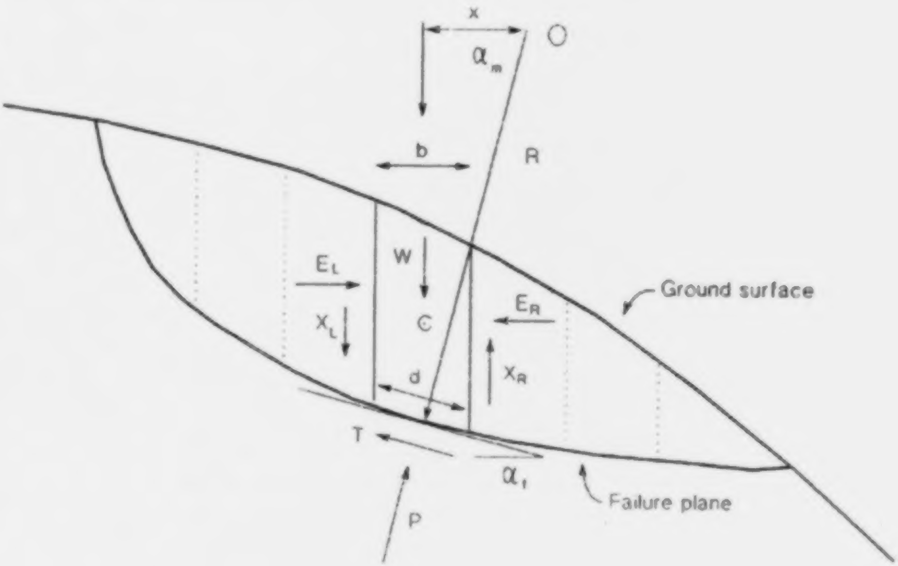
2) Gravitational stress, g - forces acting vertically downward.

3) Shear stress, τ - forces acting downward parallel to the failure plane.

4) Pore water pressure, μ - forces acting upwards perpendicular to the shearing plane.

5) Shear strength, s - forces acting upwards parallel to the failure plane.

Resolution of these forces, where the sum of the resisting forces is less than the sum of the driving forces, would indicate or suggest potential failure. Resolving these forces through variable substitution, simplification, and/or specific condition definition, has resulted in the formulation of several dozen models. Appendix 1 lists a sample of six of these models, three of which are based on failure along a planar surface, the other three are based on the curvilinear surface. The six models are briefly summarized below. The reader is referred to Shasko (1989) for other references and more detailed discussions.



α_m	angle of rotation (moment equilibrium)
α_f	slope angle tangent to the base of a slice (force equilibrium)
b	slice width
W	slice weight
P	total normal stress across the failure plane distance (d)
T	total shear stress across the failure plane distance (d)
X	interslice shear stresses on the left and right slice sides (L, R)
E	interslice normal stresses on the left and right slice sides (L, R)
x	vertical distance to the centre of the block (C)
R	arc radius
O	center of rotation
C	center of the failure block

Figure 1. Possible forces acting on a given slice for a curvilinear surface (Nash, 1987; Fan et al., 1986; Morgenstern and Sangrey, 1978.)

A: Infinite Slope Method

This planar method examines failure forces at the most basic level where conditions within the soil and force parameters are assumed constant along the slip surface. Neither tree weight against the slip surface nor the binding conditions of roots (increased soil cohesion) are accounted for. This method could represent a clearcut patch some years after harvest with root deterioration.

B: Infinite Sope Method Focusing of Vegetation Parameters

This modelling technique is similar to the one above, but includes the effects of added soil cohesion due to roots and the weight of vegetation acting downward, increasing the net shearing strength of the soil block as well as the stress on the soil caused by the vegetation. This method could provide before and after clearcut analysis where the influence of the removed vegetation and root deterioration could be monitored

C: Infinite Sopet Method Focusing on Tree Weight

This technique examines the same conditions as model B, but incorporates them in a different manner focusing on stresses caused by the inclination of the block rather than the buoyant properties of saturated soil described in model B.

D: Fellenius, Swedish, or Ordinary Method of Slices

This technique describes failure about a pivot point along a curved slip surface. Shearing stresses along each soil block slice are summed and compared to the weight of the block and its ability to rotate about the pivot point. Specification of added or variable soil or root cohesion could be included on a slice by slice basis.

E&F: Bishop's Simplified or Routine Method and Spencer's Method

These techniques also describe failure along a curved surface. Like model D, they focus on the rotational tendencies of the soil block. Additional interslice forces are added to the equations. These techniques assume that as a block moves as a set of vertical slices, forces between these slices change. Consequently, the methods require iterative solution techniques to assess stability across the block.

Each of the above models focuses on assessing the stability of a soil block by developing a measure called a factor of safety (F). F is a ratio of the shearing strength to the shearing stress. A site where these forces are equal would be in equilibrium (F=1). Where the F > 1.0, the site would be stable, and where F < 1.0, the site should have failed or would at least be unstable. Realistically, it is not possible to isolate and describe every force and component of stress and strength, nor can it be possible to assess external or 'triggering' factors, such as bedrock geology, earth tremors, burrowing animals, and long-term cyclical storms. The factor of safety, therefore, is at best a rudimentary guide which illustrates the disproportionate nature of the major force components.

Data Requirements

The factor of safety value, nevertheless, is an important primary indicator to regions of relative potential instability, provided some basic soil related data can be appropriately modelled and integrated within an analysis system such as GIS. To this end, the data requirements of the models and the models themselves were examined in terms of application, availability, accuracy, and scale of resolution. This was done in an attempt to answer the following question: "If we had an analysis system, what would be the data requirements to provide us with a basic form of stability indicators for a given model?" Variables required by each of the described models are listed in Table 1.

x - site derived parameters

o - determined from site derived parameters

A: INFINITE SLOPE METHOD

B INFINITE SLOPE METHOD FOCUSING ON VEGETATION PARAMETERS

C INFINITE SLOPE METHOD FOCUSING ON TREE WEIGHT

D FELLENIUS, SWEDISH, OR ORDINARY METHOD OF SLICES

E BISHOP'S SIMPLIFIED OR ROUTINE METHOD

F SPENCER'S METHOD

\ Model reference Parameter \	A	B	C	D	E	F
Factor of safety-planar: F_f	o	o	o			
Factor of safety-curvilinear: Fm				o	o	o
Internal angle of friction:	x	x	x	x	x	x
Shear strength: s	o	o	o	o	o	o
Shear stress: t, s	o		o	o	o	o
Shear stress across slice: T, S_m			o	o	o	
Angle of shear distortion: θ		x				
Effective soil cohesion: c	x	x	x	x	x	x
Soil and root cohesion: C_R, C_{s+t}		x	x			
Pore pressure:	o	o	o	x	x	x
Total normal stress: ¶	o	o	o	o		
Effective normal stress: ¶'						o
Stress across a slice length: P				o	o	o
Slope angle: /	x	x	x			
Angle of rotation: a				x	x	x
Slice/block length: b, l	x		x	x	x	x
Tensile strength per unit area: t_r		o				
Tensile strength per root: T_r		x				
Unit weight of water: q_w	x	x				
Soil weight-normal sat.: q_m, q	x	x	x			
Soil weight-unsaturated: q_u		x				
Soil weight-saturated: q_{sat}		x				
Proportion soil depth sat.: m_w	x		x			
Piezometric head: h, H_w	x	x	x			
Vertical soil depth: z, H	x	x	x			
Slice weight: W	o		o	x	x	x
Unit weight of vegetation: W			x			
Radius of failure arc: R				x		
Interslice stress & shear: E, X					x	x

Table 1. Data Requirements

It should be noted that for the planar models (Models A, B, and C), the number of data values required per site evaluation is no greater than the number of variables specified in the model. For example, with the infinite slope method (Model A), 9 unique observations are required to determine the total number of variables (in this case, 15) required of the model. For the curvilinear techniques (Models D, E, and F), however, multiple observations for each variable are required for each slice segment defined by the observer. In other words, while only 13 variables are required by these models, each set of variables must be collected and determined for each segment defining the soil block. Given a block definition of 6 slice segments, as many as 78 data values could be required if conditions varied completely throughout the block.

All models listed in Appendix 1 are deterministic in nature. Each requires a site-specific set of data values in order to determine a factor of safety value (F). In order to obtain an exact F value, exact measurement of all data and forces (as mentioned above) would be required. This would be possible only in a laboratory. Therefore, a compromise is sought whereby assumptions or generalities are to be made about the data and the forces involved in order to facilitate implementation. A degree of accuracy is lost, but its loss can be tolerated, given our objectives.

For the latter three rotational block models (Models D, E, F), however, it is only feasible to obtain sufficient data in a laboratory, thus we concluded that it would be next to impossible to collect sufficient and accurate data in the field to make any of the curvilinear techniques work on a routine basis for a study area within the realm of GIS. Consequently, the focus of the remaining discussion will pertain to the planar techniques.

Two types of variables are defined in Table 1, variables that are site-derived, and variables that can be calculated from site-derived data. The site derived parameters include the following:

1. slope angle,
2. the internal angle of friction of the soil,
3. the effective soil cohesion,
4. the soil depth,
5. the length of the soil block considered
6. the proportion of the soil block saturated,
7. the weights of the soil and water,
8. the height of the piezometric head (the unconfined height water would rise from the soil base), and
9. additional root and tree parameters required for methods B and C.

The question arises whether some or all of these variables can be derived from secondary sources, including terrain models, existing inventory stored in GIS, and remotely sensed imagery.

As noted earlier, slope angle is routinely obtained from digital terrain models. However, resolution and quality of the terrain model definition will control confidence in the accuracy of derived slope. Most existing terrain models will not be adequate for large scale prediction.

It should be possible to derive values for the internal angle of friction of the soil and effective soil cohesion. This can be achieved by accessing reliable available digital soil maps. We make the assumption that internal angle of friction and soil cohesion are known for a given class of forest soil type, or have been derived from samples. It is assumed further that any root/tree parameters can be estimated from other data stored in the forestry inventory. Reliability of estimates will depend on the scale and reliability of the soil map accessed.

Soil depths, to a large degree, depend on landscape morphology. Soil depth measurements derived for a number of spot samples therefore should be sufficient to interpolate soil depth over an study area given access to data layers in the GIS dealing with geology and geomorphology.

The length of the soil block is required to assess the weight of the soil block under study. If we are to consider stability criteria over a given area as a set of spot measurements, the measurement of block dimensions can be equated to a unit measure, for instance, 1 or 2m^2. By doing so, we are effectively asking 'What is the stability of a given unit block within our coverage area?'

The proportion of the soil block which is saturated is dependent on the location of the soil block in relation to topography, the recent rainfall history, watertable characteristics and the soil block's ability to store moisture. Some of this information can be derived from a terrain model and geology. Other information depends on reliable climatological records. Obviously, during and after a storm, the amount of water available for saturation is highest. Since most failure events occur in conjunction with heavy rains, a worst case planning scenario can be adopted by simply assuming 100 percent soil saturation. The exercise can be repeated for various other percentage values. This leaves the exercise of calculating probabilities of the different percentages of saturation occurring for any given study site. Assessing the probability of failure for differing saturation percentages would be useful in other decision making and forecasting applications such as road construction.

Finally, the weights of soil and water can be determined readily using the same concept as outlined in the previous paragraph. Similarly, therefore, the height of the piezometric head can be equated to the depth of the soil at 100 percent saturation (or any other specified percentage).

We observe that quite a number of the above parameters can be derived from a terrain model and other data likely to be found in a forest inventory. Other parameters, we note, can simply be set to a worst case scenario, or some other percentage, yielding slope failure probability maps for a number of different specified conditions of the ground. A concern becomes that of the quality of the data stored in the forest inventory. The assumption is made that soil inventories and data layers covering geology and geomorphology reflect the truth.

Discussion

A number of strategies exist to model slope failure prediction. Traditionally, small-scale analysis has relied on digital terrain models, while large-scale analysis has been conducted using sophisticated models that require a considerable data collection exercise.

Probability of failure prediction using digital terrain models at the most simple level is derived by flagging all slopes that exceed a specified threshold value of, say, 30 degrees. More sophisticated analysis in this category involves simple weighting of the slope by some ground characteristics, for example, soil type and vegetation coverage.

We note the feasibility of combining sophisticated modelling with relatively small-scale analyses by estimating model parameters using available digital forest inventories, where some parameters are set to worst case scenarios or some other predetermined conditions. This has the obvious advantage of increasing probability estimate reliability while reducing the costs and effort of field data collection.

Let us examine slope failure analysis at two scales, 1:1 000 and 1:10 000. At a scale of 1:1 000, for an area of 1 km², it may be possible to collect sufficient data to fully implement any of the 3 planar techniques with a 100 metre sample grid. Establishing a sample grid over the area at 100 metre intervals implies that 100 samples need to be obtained. This is a costly exercise. Sample measurements for the different variables can subsequently be interpolated to surfaces, and can be combined through overlays. The result is that a surface will have been created for every parameter required as input into the slope failure models. The actual modelling now becomes straightforward, especially if the GIS uses a raster data structure. The definition of grid size will determine the resolution and complexity of analysis. If we set our grid size, for instance, to 2 square metres, there ultimately will be 250 000 factor of safety records, and at 5m², 40 000 records (for an area of 1 km²). The resulting scalar matrix of F values will constitute a contour coverage in itself. Classifying and displaying the results can be handled easily by the GIS.

At a scale closer to 1:10 000, the resolution of the individual failure event becomes absorbed by the smallest unit measure of data we can hope to obtain or infer for a given area. For example, the area of the typical slip surface at the point of initiation is on the order of several metres square. To obtain and forecast failures at a grid cell resolution of 10's or 100's of metres square, where a large proportion of the data would be interpolated on a relatively sparse sampling set, is not a viable option. A much larger sample could be obtained but this also would not be a viable option due to the costs involved.

A preferred strategy therefore becomes one of obtaining information about soil coverage, vegetation, terrain and geology using satellite data, or digital data derived from photogrammetry or past surveys. Systematic, random or strategic sampling, however, will still be necessary to obtain estimates of reliability for the data used. The procedure for obtaining a matrix of F values thereafter will be similar to that outlined for the 1:1 000 scale analysis. However, a mechanism should be developed whereby it is possible to calculate and visualize the degree of trust placed in the reliability of slope failure prediction given uncertainty and error in input data.

We conclude that it is possible and feasible to integrate sophisticated slope modelling in GIS using available digital inventories as input data at any scale. However, we advocate a strategy of ground truthing of digital inventory to obtain indices of data quality. We advocate further that GIS need to develop mechanisms whereby uncertainty and error can be incorporated in analyses and modelling, and whereby uncertainty and data quality can be communicated to the user through visualization.

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For a more detailed bibliography, see Shasko (1989).

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Appendix 1

A: INFINITE SLOPE METHOD

Mohr-Coulomb failure criteria: $s = c' + (\sigma - \mu) \cdot \tan\phi'$

where s is the shear strength, c' is the effective soil cohesion, σ is the total normal stress, μ is the pore pressure, and ø' is the effective internal angle of friction.

The pore pressure is expressed as: $\mu = \delta_w \cdot m_w \cdot z \cdot \cos^2\beta = \delta_w \cdot h$

where δ_w is the unit weight of the water, m_w is the proportion of the soil depth saturated, z is the vertical soil depth, ß is the angle of inclination of the slope plane, and h is the piezometric head.

Normal stress: $$a = \frac{W \cdot \cos^2\beta}{b} = \frac{(\delta m \cdot z \cdot b) \cdot \cos^2\beta}{b} =$$

$$= \delta_w \cdot z \cdot \cos^2\beta$$

where W is the weight of the slice equaling the height (z) by the length (b) by the soil weight at normal moisture content (δ_m) for a unit width.

Shear stress: $$\tau = \frac{W \cdot \sin\beta \cdot \cos\beta}{b} = \frac{(\delta_m \cdot z \cdot b) \cdot \sin\beta \cdot \cos\beta}{b}$$

$$= \delta_m \cdot z \cdot \sin\beta \cdot \cos\beta$$

Factor of safety: $$F = \frac{s}{\tau} = \frac{c' + (\delta_m z \cdot \cos^2\beta - \mu) \cdot \tan\phi'}{\delta_m \cdot z \cdot \sin\beta \cdot \cos\beta}$$

substitute for μ, $$F = \frac{c' + (\delta_m - m_w \cdot \delta_w) \cdot z \cdot \cos^2\beta \cdot \tan\phi'}{\delta_m \cdot z \cdot \sin\beta \cdot \cos\beta}$$

Notes: The length of the slope is assumed to be of infinite distance. Water flow or seepage is parallel to the slope of the failure plane. (Conventionally, lambda is used instead of delta.)

Source of equations: Selby (1982) and Nash (1987).

B: INFINITE SLOPE METHOD FOCUSING VEGETATION PARAMETERS

Mohr-Coulomb failure criteria: $s = c' + (\sigma - \mu) \cdot \tan\phi'$

where s is the shear strength, c' is the effective soil cohesion, σ is the total normal stress, μ is the pore pressure, and ø' is the effective internal angle of friction.

Shear strength reflects the individual cohesion components:

$$s = C_e + C_R + (\sigma - \mu) \cdot \tan\phi'$$

where C_e is the effective cohesion of the soil and C_R is the cohesion derived from the root system.

Shear strength due to the roots:

$$C_R = t_R[\cos\theta \cdot \tan\phi + \sin\theta]$$

where θ is the angle of shear distortion, ø is the angle of internal friction, and t_R is the average tensile strength of the roots per unit area of soil:

$$t_R = T_R \cdot A_R/A$$

where T_R is the tensile strength of the roots (psi) and A_R/A is the ratio of the area occupied by roots to the total cross sectional area.

Factor of safety: $$F = \frac{\left[\dfrac{C_e + C_R}{\tan\phi' \cdot \cos^2\beta} + (q_o + \delta \cdot H) + (\delta_B - \delta) \cdot H_w\right] \cdot \dfrac{\tan\phi'}{\tan\beta}}{[(q_o + \delta \cdot H) + (\delta_{sat} - \delta) \cdot H_w]}$$

where q_o is the vertical surcharge or weight of the vegetation, δ is the density of the moist soil, H is the vertical soil depth, ß is the slope angle, δ_B is the buoyant density of the soil ($\delta_B = \delta_{sat}$ - water density), and H_w is the height of the piezometric head.

Notes: The length of the slope is assumed to be of infinite distance. Water flow is parallel to the slope of the failure plane. Gray and Megahan refer to the shear strength derived from the roots as pseudo cohesion.

Source of equations: Gray and Megahan (1981).

C: INFINITE SLOPE METHOD FOCUSING ON TREE WEIGHT

Mohr-Coulomb failure criteria: $s = c' + (\sigma - \mu)\cdot\tan\phi'$

where s is the shear strength, c' is the effective soil cohesion, σ is the total normal stress, μ is the pore pressure, and ϕ' is the effective internal angle of friction.

Apparent cohesion due to the roots: $s = c_{s+t} + (\sigma - \mu)\cdot\tan\phi'$

where s+t is the shear strength of the soil plus the roots.

The pore pressure is expressed as:

$$\mu = \delta_w\cdot m_w\cdot z\cdot\cos^2\beta = \delta_w\cdot h$$

where δ_w is the unit weight of the water, m_w is the proportion of the soil depth saturated, z is the vertical soil depth, β is the angle of inclination of the slope plane, and h is the piezometric head.

Normal stress: $\sigma = \dfrac{W\cdot\cos^2\beta}{b} = \dfrac{(\delta_m\cdot z\cdot b)\cdot\cos^2\beta}{b} = \delta_m\cdot z\cdot\cos^2\beta$

where W is the weight of the slice equaling the height (z) by the length (b) by the soil weight at normal moisture content (δ_m) for a unit width.

Normal stress including the weight of the trees:

$$\sigma = (\delta_m + T)\cdot z\cdot\cos^2\beta$$

where T is the weight of the trees.

Shear stress: $\tau = \dfrac{W\cdot\sin\beta\cdot\cos\beta}{b} = (\delta_m\cdot z + T)\cdot\sin\beta\cdot\cos\beta$

Factor of safety: $F = \dfrac{s}{\tau} = \dfrac{c_{s+t} + [(\delta_m\cdot z + T)\cdot z\cdot\cos^2\beta - \mu]\cdot\tan\phi'}{(\delta_m\cdot z + T)\cdot\sin\beta\cdot\cos\beta}$

substitute for μ:

$$F = \frac{c_{s+t} + [(\delta_m\cdot z + T) - (m_w\cdot z\cdot g_w)\cdot\cos^2\beta\cdot\tan\phi'}{(\delta_m\cdot z + T)\cdot\sin\beta\cdot\cos\beta}$$

Notes: The length of the slope is assumed to be of infinite distance. Water flow or seepage is parallel to the slope of the failure plane.

Source of equations: Selby (1982).

D: FELLENIUS, SWEDISH, OR ORDINARY METHOD OF SLICES

Mohr-Coulomb failure criteria: $s = c' + (\sigma - \mu)\cdot\tan\phi'$

where s is the shear strength, c' is the effective soil cohesion, σ is the total normal stress, μ is the pore pressure, and ϕ' is the effective internal angle of friction.

Total normal stress across the slice length:

$$P = a\cdot l = W\cdot\cos\alpha$$

where W is the weight of the slice, l is the slice length and a is the angle of rotation from the center of rotation to the center of the base of the slice.

Total shear stress across the slice length:

$$T = \tau\cdot l = \frac{s\cdot l}{F} = \frac{c'\cdot l + (P - \mu\cdot l)\cdot\tan\phi'}{F}$$

where τ is the shear stress and F is the Factor of Safety.

Equilibrium moment: $\Sigma(W\cdot x) = \Sigma(T\cdot R)$ $\quad x = R\cdot\sin\alpha$

$$\Sigma(W\cdot\sin\alpha) = \Sigma(T)$$

where x is the horizontal distance form the centroid of each slice to the center of rotation and R is radius of the failure arc.

Factor of Safety (moment): $F_m = \dfrac{\Sigma[c'\cdot l + (P - \mu\cdot l)\cdot\tan\phi']}{\Sigma(W\cdot\sin\alpha)}$

substitute for P...

$$F_m = \frac{\Sigma[c'\cdot l + (W\cdot\cos\alpha - \mu\cdot l)\cdot\tan\phi']}{\Sigma(W\cdot\sin\alpha)}$$

Notes: Rotation of the failure occurs along a curvilinear slip surface. Interslice forces are assumed to be parallel to the base.

Sources of Equations: Bromhead (1986), Morgenstern and Sangrey (1978), and Nash (1987)

E: BISHOP'S SIMPLIFIED OR ROUTINE METHOD

Mohr-Coulomb criteria: $s = c' + (\sigma - \mu)\cdot\tan\phi'$

where s is the shear strength, c' is the effective soil cohesion, σ is the total normal stress, μ is the pore pressure, and ϕ' is the effective internal angle of friction.

Total shear stress across the slice length:

$$T = \tau\cdot l = \frac{s\cdot l}{F} = \frac{c'\cdot l + (P - \mu\cdot l)\cdot\tan\phi'}{F}$$

where t is the shear stress and F is the Factor of Safety.

Total normal force resolved in the direction normal to the slip surface:

$$P = (W + X_n - X_{n+1})\cdot\cos\alpha - (E_n - E_{n+1})\cdot\sin\alpha$$

When external forces acting on the slope are in equilibrium:

$$\Sigma(X_n - X_{n+1}) = 0, \quad \Sigma(E_n - E_{n+1}) = 0$$

where X_n and X_{n+1} are the interslice shear forces and E_n and E_{n+1} are the interslice normal forces.

Effective normal force: $$P' = P - \mu\cdot l = \frac{W - l\left[\mu\cos\alpha + \dfrac{c'\cdot\sin\alpha}{F}\right]}{\cos\alpha + \dfrac{\sin\alpha\cdot\tan\phi'}{F}}$$

where W is the weight of the slice, l is the length of each slice, and α is the slope angle tangent to the center of the base of the slice.

Equilibrium moment:

$$\Sigma(W\cdot x) = \Sigma(T\cdot R), \quad x = R\cdot\sin\alpha, \quad \Sigma(W\cdot\sin a) = \Sigma(T)$$

where x is the horizontal distance form the centroid of each slice to the center of rotation and R is radius of the failure arc.

Substitute for T, re-arrange for F...

Factor of Safety (moment): $$F_m = \frac{\Sigma[c'\cdot l + P'\cdot\tan\phi']}{\Sigma(W\cdot\sin\alpha)}$$

Notes: Failure is examined through the rotation of the failure block along a curvilinear slip surface (F_m). Interslice shear stresses are assumed to equal zero and interslice normal stresses are negated. The effective normal stress (P') contains the factor of safety, thus it requires iterative processing to solve.

Sources of Equations: Bishop (1955).

F: SPENCER'S METHOD

Mohr-Coulomb criteria: $s = c' + (\sigma - \mu)\cdot\tan\phi'$

where s is the shear strength, c' is the effective soil cohesion, σ is the total normal stress, μ is the pore pressure, and ϕ' is the effective internal angle of friction.

Total mobilization shear stress across the slice base:

$$S_m = \frac{S}{F} = \frac{c'\cdot b}{F}\cdot\sec\alpha + P'\cdot\frac{\tan\phi'}{F} = \frac{c'\cdot b\cdot\sec\alpha + P'\cdot\tan\phi'}{F}$$

where S is the total shear stress available (s·l, the slice length), b is the slice width, and P' is the effective normal stress at the slice base, α is the angle of rotation, and W is the weight of the slice.

Factor of Safety: $$F = \frac{\Sigma[c'\cdot b\cdot\sec\alpha + \tan\phi'\cdot(W\cdot\cos\alpha - \mu\cdot b\cdot\sec\alpha)]}{\Sigma(W\cdot\sin\alpha)}$$

The resultant of two interslice forces:

$$Q = \frac{\dfrac{c'\cdot b}{F}\cdot\sec\alpha + \left[\dfrac{\tan\phi'}{F}\right](W\cdot\cos\alpha - \mu\cdot b\cdot\sec\alpha) - W\cdot\sin\alpha}{\cos(\alpha-\theta)\left[+\dfrac{\tan\phi'}{F}\cdot\tan(\alpha-\theta)\right]}$$

where θ is the slope of the resultant of a pair of interslice forces.

External forces (force equilibrium):

$\Sigma(Q\cdot\cos\theta) = 0$ [corresponding to $E_L - E_R = 0$]

$\Sigma(Q\cdot\sin\theta) = 0$ [corresponding to $X_L - X_R = 0$]

In an equilibrium state, the sum of the horizontal and vertical interslice forces must equal zero. Assuming that the interslice forces are parallel (θ remains constant) then both forces are equivalent to:

$$\Sigma Q = 0$$

External forces (moment equilibrium):

$$\Sigma[Q\cdot\cos(\alpha-\theta)] = 0$$

Solution: F is obtained when $\Sigma Q = \Sigma[Q\cdot\cos(\alpha-\theta)]$ for a given θ.

Notes: Failure is examined through the movement of the soil block along a curvilinear slip surface. The final factor of safety value is reached iteratively based on a constant slope of the resultant of the pairs of interslice forces.

Sources of Equations: Spencer (1967) and Nash (1987).

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Assessing the Effects of Military Aircraft Overflights: A Spatial Analysis Approach Based on a Geographic Information System

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Abstract

A Geographic Information System (GIS) provides an excellent tool for assessing the viability of land use practices. One area which has received little attention is the assessment of potential conflicts resulting from aircraft overflights along Military Training Routes (MTR). Conflict arises when populations encroach on existing training routes or when the military wishes to create new ones. This paper utilizes GIS technology together with a noise modeling program to assess the potential impact of noise generated by low flying military aircraft. The capacity to perform this type of analysis will enhance the current decision making process in planning low-level corridors by providing military and civilian environmental planners with accurate and timely information upon which to base their decisions.The prototype system will also allow the analysis of proposed training routes and make recommendations as to possible ways to deal with the potential impact of aircraft noise on the human population.

Study Objective

The objective of this study is to evaluate the utility of an integrated GIS and noise prediction system utilizing three primary analysis procedures:

1. Assessing the impact of new mission requirements on existing Military Training Routes,
2. Determining the location and impact of proposed Military Training Routes, and
3. Predicting the portion of the population that would be highly annoyed by differing noise levels.

Introduction

Assessing the environmental impact of its practices has long been a priority of the United States Air Force. Perhaps this agency's greatest concern is maintaining the safety and welfare of the public and Air Force personnel. Through the implementation of stringent environmental guidelines and planning procedures, the Air Force strives to eliminate any potential harm their operations might cause to humans or the environment. The Air Force is very interested in determining the potential impact of aircraft noise on humans and the surrounding environment. They have conducted extensive research in this area and have contributed greatly to the understanding of noise and its effects. The Day-Night Sound Level, one of four sound descriptors used by the Environmental Protection Agency to determine the impact of noise on public health and welfare, was developed by the Air Force (Speakman, 1990).

The Air Force has established procedures to assess and mitigate conflicts that arise from aircraft noise in the areas surrounding air bases. All air bases are required to perform an

Air Installation Compatible Use Zone assessment or an AICUZ. An AICUZ is carried o ut to evaluate whether or not current or proposed operations will come into conflict with surrounding landuse or adversely effect public welfare (USTAC, 1990).

Historically, the need for a comprehensive, automated set of procedures for assessing and mitigating noise impacts along low-level training routes was not necessary. In the past, these routes were located in remote regions of the country where few people visited, much less lived. However, this is no longer true, as population growth, the increased use of public lands, and the realization that aircraft noise may have detrimental effects on animals, have created the need for a system similar to the AICUZ program for use with training routes (Knickerbocker, 1986; Knudson and Bowman, 1988; Nixon et al., 1968).

Over time, the nature of military aircraft and air warfare tactics have changed. Aircraft are faster and more maneuverable and, at the same time, the radar and satellite tracking systems used to locate aircraft have become more sophisticated. In order to avoid these highly sensitive tracking systems, pilots are forced to fly at lower altitudes. This, along with the fact that faster flying aircraft require more space to maneuver, has the Air Force actively seeking to increase the number of low-level routes available for training (Knickerbocker, 1990).

Definitions

Military Training Route (MTR) - MTRs can be considered airspace set aside for use by the military for training purposes. An MTR consists of a route centerline and route corridor boundary. The route may be straight or it may have turnpoints along the centerline. Routes are normally divided into segments to allow operation parameters and restrictions to be implemented as needed. The routes can be anywhere from 100 to 1000 nautical miles(nm) long, corridor widths range from 0.5nm up to 10nm, while the minimum altitude above ground level is 100 to 600 feet (USTAC, 1990).

Noise - The EPA defines noise as unwanted sound. In the context of protecting the public health and welfare, noise implies adverse effects on people and the environment. Noise causes hearing loss, interferes with human activities at home and work, and is in various ways injurious to people's health and well-being. Although hearing loss is the most clearly measurable health hazard, noise is also linked to other physiological and psychological problems.Thus, the numerous effects of noise combine to detract from the quality of peoples lives and the environment (EPA, 1978).

Sound - Sound is a result of a source inducing vibrations in the air, resulting in sound waves. There are three major components of sound:

1. Amplitude (perceived as loudness),
2. Frequency (perceived as pitch), and
3. Time Pattern

Amplitude is the component of sound most commonly used to measure noise. Amplitude, according to the EPA, is the sound pressure, or, a measure of the difference between atmospheric pressure with no sound and the total pressure with sound. Sound pressure is the basic component of the sound descriptors used to measure environmental noise.

The unit of sound pressure is the decibel or dB. Because the range of sound intensities is so great, it is convenient to compress the scale of measurement to encompass all the sounds that need to be measured. A logarithmic scale allows this to be done; therefore , the decibel scale is not a linear one. Sharply painful sound is 10 million times greater in sound pressure than the least audible sound. This 10 million to 1 ratio is simplified logarithmically to 140 dB. An important property of the decibel scale is that sound pressure levels are not directly additive. For example, if a sound of 70dB is added to another sound of 70dB, the total is only 73dB, not 140dB. If sounds of different levels are added the lower level sound adds less to the higher level sound as the difference between the two increases. If the difference is 10dB or higher, then adding the two sounds will result in little or no increase in the total sound level (EPA 1978).

The ability to hear a sound depends greatly upon the frequency composition of the sound. People hear sounds more easily when the sound energy occurs at frequencies between 1000 and 6000 Hertz. To measure sound on a scale that approximates the way it is heard by people, more weight must be given to the frequencies that people hear most easily. Many different weighted scales of sound measurement , including A, B, C, D, and E-weighted sound scales have been developed. The A-weighted scale is recommended by the EPA to describe environmental noise because it is accurate in most cases, it is convenient, and is used extensively throughout the world. An A-weighted decibel value used by itself denotes either a sound at a given instant, a maximum level, or a steady-state level, whereas the sound descriptors used in this study measure sounds which vary over time (EPA 1978).

Sound Descriptors

The Equivalent Sound Level (L_{eq}) is a method of quantifying the noise environment by determining the value of a steady-state sound which has the same A-weighted sound energy as a time-varying sound. The Equivalent Sound Level is a single value of sound for any desired location, which includes all the time-varying sound energy in the measurement period. The major advantage to the Equivalent Sound Level is that it correlates reasonably well with the effects of noise on people, even for wide variations in sound levels and time patterns. It is used when only the duration and levels of sound are relevant. It is, however, the basis for another sound descript or which does account for the time of day at which the noise occurs (EPA, 1978).

The Day-Night Sound Level (L_{dn}) is the A-weighted equivalent sound level for a 24-hour period with an additional 10dB weighting imposed on the equivalent sound levels which occur during nighttime hours, 10pm to 7am (EPA, 1978).

While the Equivalent Sound Level is a basis for the Day-Night Sound Level, the Day-night Sound Level is in turn the basis for a third descriptor. The Noise Onset-Rate adjusted Monthly Day-Night Sound Level or L_{dnmr} was developed by the Air Force to specifically address noise generated by low-level, high speed aircraft flying on MTRs. The L_{dnmr} is identical to the L_{dn} except it applies a penalty of up to 5dB for events with a startle effect (i.e., those with a fast onset rate). The more sudden the rate of noise onset, the greater the penalty applied (USAF, 1990; Lucas and Plotkin, 1988).

Hardware/Software

The GIS used for this analysis was Environmental Systems Research Institute's ARC/INFO, version 5.0, running on a Data General MV2000 mini computer.

The noise modeling program used was ROUTEMAP, developed by Wyle Laboratories for the Harry G. Armstrong Aerospace Medical Research Laboratory, Air Force Systems Command Wright-Patterson Air Force Base, Ohio. ROUTEMAP is a PC based menu-driven program that calculates noise levels on the ground along a given flight path.

The program utilizes three noise matrices; the equivalent sound level or L_{eq}, the day-night sound level or L_{dn}, and the onset rate, adjusted monthly day-night average A-weighted sound level or L_{dnmr}. This last noise metric is the one primarily used by ROUTEMAP (Lucas and Plotkin, 1988).

ROUTEMAP requires the Air Force planner to input the operation parameters for the route being studied. These parameters include:

Mission type (instrument, visual flying rules, or special operations),
Aircraft type,
Aircraft operating power,
Vehicle (aircraft) velocity,
Altitude above ground level (AGL), and
Number of day and night monthly sorties.

ROUTEMAP can produce five forms of output:

1. A table specifying the noise levels in decibels as a function of the distance from the flight path for any one or all three noise metrics,

2. The information from the tables can be sent to a plot program to produce noise contours,

3. ROUTEMAP will calculate, for a particular noise level, the probability of highly annoying the population,

4. The program will calculate, for a location on the ground, the cumulative effects of two or more noise events, and

5. ROUTEMAP will rank noise contributors.

Threshold Values

A landuse compatibility threshold of 74dB, for a 24-hour period was arrived at through a literature review and personal discussions with an Air Force noise specialist. This value is a compromise between the value specified by EPA noise level documents and the value the noise specialist feels will provide the necessary protection with an adequate margin of safety (Speakman, 1991). The EPA documents indicate that above 73dB permanent hearing loss could occur for at least a portion of the population while the Air Force specialist considers 75dB as the threshold value.

Study Area

The study area comprises some 17 500 square miles of western Idaho. This area includes Mountain Home Air Force Base, the Sailor Creek Gunnery Range, and portions of five existing MTRs. The area was chosen because of its diverse landscape.

The Boise metropolitan area is centrally located within the study area, along with the cities of Caldwell and Nampa. These three cities and the surrounding area had an estimated population of 300,000 in 1986 (US Census Bureau, 1988). Many small communities, with populations ranging from 2000 -10 000, are located throughout the study area.

Data

1. Land use Sources (1:100 000)
    a. Agriculture
        1. cropland
        2. rangeland
    b. Urban buildup
    c. Small communities

Agricultural landuse	- Soil Conservation Service
Urban buildup	- Idaho Department of Transportation - Soil Conservation Service
Small Communities	- Idaho Department of Transportation - Soil Conservation Service

2. Population Sources
population > 2000 - U.S Census Bureau City/County Data Book, 1988 population < 2000 - Rand McNally United States Road Atlas, 1989

3. Route Operation Parameters and Sources
    a. Aircraft operating power
    b. Aircraft type
    c. Aircraft velocity
    d. Altitude above ground level
    e. Mission type (instrument, special operations, visual)
    f. Number of daytime and nighttime monthly sorties

Sources:
All parameters are obtainable from
- ROUTEMAP data files, aircraft specifications, and the mission planner or airspace manager

Analysis Procedures

Assessing the impact of new mission requirements on existing Military Training Routes.

Stage I

The need for new mission requirements must be determined and stated in terms of route operation parameters.

For instance, on December 29, 1988, the Commission on Base Realignment and Closure, established by United States Secretary of Defense , recommended the realignment and closure of 145 military installations. The Commission recommended that George AFB in Southern California be closed and the training wing, consisting of 94 F-4G aircraft, be transferred to Mountain Home AFB in southern Idaho. The new aircraft will result in increased use of the established low-level training routes in and around Idaho (USTAC, 1 990).

Once the need for altering the mission of the training route(s) is established, the alterations must be expressed in terms of route operation parameters (i.e., type of aircraft, number of sorties, aircraft power setting, etc.). The parameters for the new aircraft are then entered into ROUTEMAP and the combined effects of all aircraft using the selected low-level route(s) can be determined.

Stage II

ROUTEMAP is run at this stage, using the route operation parameters for the new training mission to create a **Noise Contour** coverage. The contours are created from the initial ROUTEMAP output which is a table of noise level versus distance from route centerline. This table is imported into ARC/INFO and used by the BUFFER command. The buffer operation uses the distance from the route centerline as the buffer distance to generate the contours. The coverage created by the buffer command has polygon topology with the area between contours representing noise classes or zones (i.e., 65 - 70dB, 70 - 75dB).

Stage III

Noise emanates from many different sources such as construction noise, household noise, industrial noise, and transportation noise. It is important, then, to examine the total range and combination of noise sources.

For this reason, the **Noise Zone** coverage is overlaid with landuse to facilitate the combining of ambient noise levels for each land use with the noise values calculated by ROUTEMAP. This results in a **Total Noise** coverage with a value representing the overall noise level for each landuse.

The areas of the coverage that exceed the threshold value can then be shaded according to the extent to which they surpass 74dB. For instance, using increments of 2dBs shade the areas which fall within the 74 - 76dB range lighter than those areas having a value between 78 - 80dB. This will show the planner which areas need the greatest amount of mitigation to bring the noise level down to an a cceptable level.

For the initial analysis, only four land use type are distinguished; urban, small communities, cropland, and rangeland. This is due to the 1:100 000 map scale used for the initial analysis; any attempt to break these categories down further would be unrealistic. If necessary, a more detailed land use layer could be generated at a larger map scale to include more land use categories. In areas with greater population densities this might be required to accurately portray ambient noise levels.

Determining the location of proposed Military Training Routes.

This analysis would require more detailed population statistics. Census tracts or census blocks may be used as the resolution unit for the mapping. If tracts are used, the current scale could be maintained, however, if census blocks were used, a larger map scale such as 1:24 000 - 1: 50 000 would be acceptable.

Stage I

The whole idea in placing a training route is to avoid human population. In order to facilitate this, a **Population Density** coverage will be created using the census tract or block data. The tracts or blocks will be shaded according to the density, with lower densiti es being lighter than higher density areas.

Stage II

At this stage, the **Population Density** coverage is brought up on the screen and the planner can then interactively place the route in the low density areas. The final route location may not be completely within the low density areas because the route corridor can be any where from 0.5nm up to 10nm in width. However, through this method the planner should be able to optimize the route in terms of its location in relation to the human population.

Once the proposed route is properly located, it can be run through the other analysis procedures previously outlined for existing routes, to determine whether it is compatible with other land uses.

ROUTEMAP's annoyance prediction capabilities were utilized to create a table of noise level versus percentage of the population highly annoyed.

Once the percentages are calculated, the table can be referenced to determine the number of people falling under a particular noise level who would be highly annoyed. This analysis would require the **Total Noise** coverage to be overlaid with the **Population** coverage.

Expected Results

Tabular data consists of the following:

1. Percentage of land area impacted by a particular noise level, broken down by land use category, for each training route analyzed,
2. Net gain or lose of land area impacted between old and new route operation parameters.,
3. Noise level versus percentage of the population highly annoyed, for use in calculating the number of persons impacted by the different noise levels,
4. Number of persons highly annoyed by varying noise levels, for each training route analyzed,
5. Comparison of results of running ROUTEMAP with different scenarios for the route operation parameters, and
6. Report specifying the route operation parameters which result in the least amount of impact on current land use.

Map output can be generated for any of the tabular data.

Further Analysis

Mitigation can occur only within the confines of the training mission. Mitigation is achieved by altering the route operation parame ters on the entire route or just those route segments which come into conflict with current land use.

There are three main parameters that can be modified to reduce the impact of the aircraft noise, flight tract, aircraft power setting and aircraft altitude.

The flight tract can be offset from its original position to avoid noise sensitive areas that fall directly under the flight path. It is also possible to mitigate impact at the edges of the route in this manner.

The aircraft power setting can be reduced, which in turn reduces the noise signature of the aircraft. The power setting is the same as the throttle on an automobile or motorcycle; the higher the power setting, the louder the engine noise.

Increasing the altitude of the aircraft is another way to mitigate impact directly beneath the flight tract, as the altitude above ground level or AGL increases the noise level below the aircraft decreases. However, due to a decrease in lateral attenuation, the overall area impacted by the aircraft noise path increases as the AGL increases. The noise path spreads out to the sides of the airplane. Of course, the inverse is also true, by decreasing the AGL, lateral attenuation increases, reducing the overall area beneath the noise path of the aircraft. Lateral attenuation is the combined effect of atmospheric absorption, wave divergence , the ground and meteorological conditions, forward flight of the aircraft, and engine/airplane location. All these factors reduce the distance from the side of the aircraft that engine noise can be heard.

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An Application of Spatial Analysis to Fisheries Acoustics

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Abstract

The harvesting of fishing stocks is regulated by quotas that are often set on the basis of catch statistics, population models and past experience. Acoustic methods, such as sonar and echo sounding, can provide direct population estimates and information on fish behaviour that allow a better understanding and management of the resource.

Fisheries acoustic data exhibit many of the characteristics of data for which Geographic Information Systems have successfully provided powerful analytic capabilities. Until very recently, application tools to display, manipulate and quantitatively analyze fisheries acoustic data as images were lacking. This paper describes a new analysis procedure for fisheries acoustic data that uses the COMPUGRID Spatial Analysis System.

A typical rockfish echogram is used to illustrate the process. Rockfish provide a suitably difficult example including a high school density, a steep ocean bottom and the close proximity of schools to the bottom. Various spatial analysis techniques, such as ALGEBRA, AVERAGE, BUFFER, CLIP, MEASURE, OVERLAY, PAINT and SLIVER, are used to recognize bottom and to define and analyze individual fish schools. This analysis could not have been done with traditional acoustic processing methods.

Introduction

Fisheries acoustic data have similarities to land use data and satellite imagery that have attracted us to explore the use of a Geographic Information System (GIS) for their display and analysis. We have used GIS tools to develop a new procedure for the analysis of fisheries acoustic data that allows us to define and analyze individual fish schools.

Traditional fisheries acoustic instruments include sonar and echo sounding equipment that produce crude images of the underwater situation. Echo sounder data are displayed as echograms that show a vertical profile of the water column; depth and the presence of fish schools are clearly shown. A typical rockfish echogram is used to illustrate the new analysis procedure and to demonstrate its ability to isolate and quantify fish schools. The sample data were acquired during a rockfish research cruise off northern Vancouver Island (Leaman et al., 1991).

Echograms are numeric matrices that can be displayed as raster images. Spatial analysis tools (Tomlin,

1990) can then be used to enhance important features such as ocean bottom, fish schools, single fish or plankton. When treated as a map of fish density, echograms provide the basis for quantitative analysis of significant structures such as fish schools.

In contrast to the analysis of individual schools, conventional acoustic data processing techniques are only able to provide average information, such as fish density for a given distance-depth interval. Much more information can be obtained when fish school boundaries are defined objectively and overlay techniques are used to measure individual school characteristics such as density, biomass or periphery.

We have used the Compugrid Spatial Analysis System (Langford, 1990). It provides the building blocks for our analysis. Only minor custom modifications were required.

Work is in progress to apply our school recognition and analysis procdure to an encompassing set of echograms. In this paper, we describe our school analysis procedure on the basis of a typical echogram.

Data collection

The data were collected with a scientific echo sounder system consisting of a transducer, echo sounder, chart recorder and a PCM/VCR analog tape recorder. Black and white echograms were generated and conventional fisheries acoustic analysis procedures were carried out while at sea. The echo sounder is characterized by: carrier frequency 38 kHz, transmit pulse length 0.6 ms, power 1000 W, transmit pulse repetition (ping rate) 1 Hz, time varied gain 20 log R (Kieser et al. 1987; Cay and Medwin 1977; Mitson 1983).

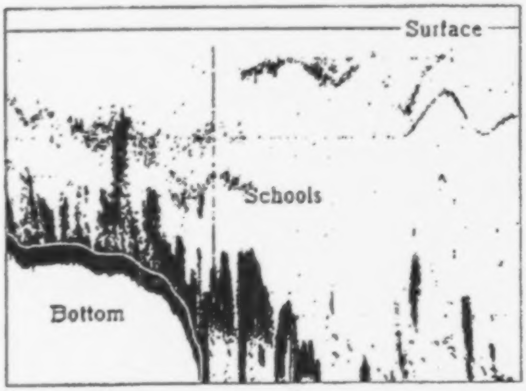

Figure 1. Rockfish echo data. Surface, bottom and fish schools are shown. Distance and depth are along the horizontal and vertical axes respectively.

Following the cruise, data were played back from analog tapes and digitized with a special purpose data logger that generates a binary echo file. All signals that exceed a user selected threshold and are located between the transducer and the bottom are recorded. Typically, an echo is received every second, A/D conversion proceeds at 7.5 kHz, generating an echo voltage for every 0.1 m depth (Kieser, 1985).

Typical raster images are stored one frame per file, with scans written from top to bottom. In contrast, echograms are written from left to right and represent a continuous record. A data conversion program was developed to break the echo data into discrete images and to convert these into a suitable format for GIS raster processing. As the echo voltages have a dynamic range from 10 to 10 000 mV, they are readily accommodated as integer values.

For our hardware, a typical screen image accommodates 13 minutes distance by 56 m depth, corresponding to 780 echoes by 560 depth intervals. Ultimately, image size is limited by available memory and/or screen resolution. Memory, at present, limits us to 2048 scans by 2048 pixels. Beyond these limits, adjacent pings or depth layers can be averaged to accommodate larger portions of the echogram. Generally, little averaging is required; thus the raster image is a nearly complete quantitative representation of our echo data. Conventional and specialized GIS tools can now be used to analyze our data.

Description of data analysis procedure

A. Bottom Recognition and Removal

Usually the echo from the ocean bottom is much stronger than that from individual fishes or schools. The bottom echo must be identified and removed before fish echoes can be analyzed.

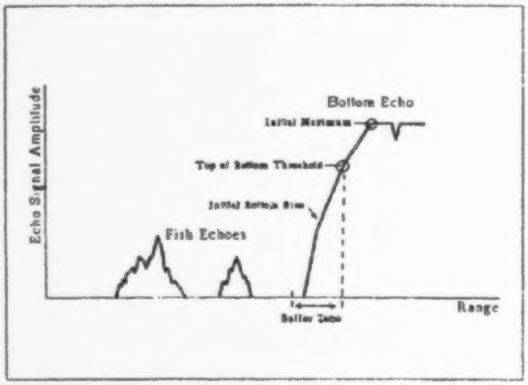

Figure 2. Plot of a single ping showing echo amplitude (vertical axis) versus ocean depth (horizontal axis). Fish schools and bottom are indicated.

We detect the bottom echo on the basis of its relatively large signal. Unfortunately, there may be gaps in the bottom, or fish schools may occasionally give equal or stronger echoes.

To perform bottom recognition and removal, we use the following procedure:

1. ALGEBRA to threshold data at 80% of maximum amplitude;
2. AVERAGE over several pixels to suppress occasional large echoes from schools. Several passes may be used;
3. ALGEBRA to threshold data again at 80% of maximum amplitude. Presumably only the bottom echo remains;
4. BUFFER bottom echoes to generate a preliminary bottom mask;
5. CLIP to extract bottom echoes from raw data;
6. AVERAGE to suppress random ping to ping variation;
7. Create a bottom mask using a special bottom mask program;
8. BUFFER bottom to create final bottom mask. This assures that only fish echoes remain above the mask; and
9. CLIP the bottom from the echo data to leave only fish data.

The first five steps are designed to suppress fish echoes and extract the bottom echoes from the data. The remaining steps generate a bottom mask which can be used to remove all bottom echoes, thus creating a fish file.

The steps described above use the standard spatial analysis tools: ALGEBRA, AVERAGE, BUFFER and CLIP. Only the bottom mask, step 7, requires a special program called BTRK (Bottom TRacK).

BTRK works on a subset of echo data that only contains averaged echoes from the bottom and its immediate vicinity. A first pass locates the first maximum echo in each ping. This will be the strongest echo that occurs just below the bottom. A second pass works upwards from the maximum echo to locate the 'top of bottom threshold' which indicates the upper edge of bottom.

BTRK and the subsequent BUFFER process create a bottom mask in which four zones are delineated:

1) below maximum bottom echo,
2) maximum bottom echo,
3) maximum bottom echo to top of bottom threshold, and
4) top of bottom threshold to top of buffer.

Zone 4 needs to be included in the bottom mask to remove the initial rise of the bottom echo. It provides protection on steep slopes were the bottom signal may rise particularly slowly, fills possible gaps in the bottom mask and to give a smoother top edge.

Finally, the echo data under the bottom mask are removed, leaving only fish data. This is the starting point for school analysis.

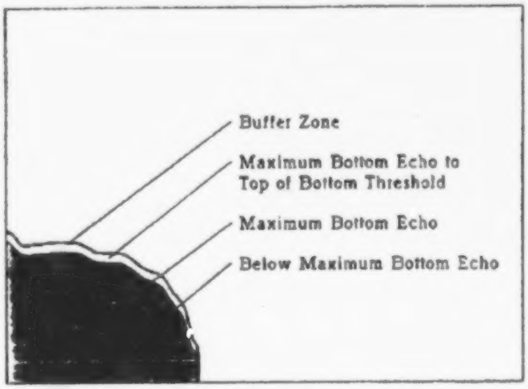
Buffer Zone
Maximum Bottom Echo to Top of Bottom Threshold
Maximum Bottom Echo
Below Maximum Bottom Echo

Figure 3. The final bottom mask shows 1) an area below maximum bottom echo, 2) maximum bottom echo, 3) area from maximum to top of bottom threshold and finally 4) a buffer zone to isolate fish echoes from the initial rise of the bottom echo.

B. School Recognition and Analysis

For our purposes a school is defined as a coherent aggregation of fish. A fish school is easily delineated if it has a simple boundary, is well separated from other structures and has a significant fish density. Figure 1 illustrates some typical fish schools of complex shape. The apparent school shape depends on several parameters including the recorder gain. Generally schools will appear larger with increased gain. Shape also will vary unless the school is of uniform density. Several additional parameters are required to define a school, a precise algorithm is needed to achieve a consistent definition.

The objectives of school analysis are to recognize fish schools on the basis of a set of well defined criteria and to measure a number of characteristic properties for each school. It is anticipated that these measurements will provide a basis for school classification (Richards, et al. 1991). As an example, consider fish density in a school. It is well known that herring schools are much denser than aggregations of other fishes, thus density can potentially be used to identify herring.

Using the echogram from our rockfish test data, the following school recognition and analysis procedure was developed:

1. ALGEBRA to threshold data at 5% of maximum amplitude;
2. BUFFER to consolidate isolated portions of a school and to generate a preliminary school mask;
3. CLIP bottom from preliminary school mask;
4. Perform specialized school recognition to generate a final school mask; and
5. Analyze schools for characteristic parameters.

School Analysis Report

Echo File: 22012S.ROW
School Mask: ZS.ROW
Edge/Label Mask: ZS.LBL
Minimum School Size: 450

School	Total	Volume			--- Start ---			--- End ---		
Number	Pixels	Density	Area	Perimeter	Sequence	Ping	Depth	Sequence	Ping	Depth
1	2893	518.936	5786.000	2610.789	16	8	002	17	15	1340
2	4583	1731.290	9166.000	4670.395	17	46	018	20	53	1134
3	2824	904.994	5648.000	3850.384	21	40	1056	23	40	1278
4	1380	217.638	2760.000	1901.596	12	1	1130	13	15	1246
5	55219	122600.400	110438.000	20735.710	12	1	1176	19	55	2002
6	799	217.643	1598.000	1483.600	23	48	1200	25	0	1276
7	692	54.910	1384.000	1265.600	17	16	1222	18	5	1298
8	4519	1601.583	9038.000	4469.196	15	56	1346	18	26	1520
9	480	56.981	960.000	658.001	13	44	1408	14	6	1470
10	2189	1987.994	4378.000	1354.400	21	57	1614	22	28	1864
11	2487	3535.006	4974.000	1152.803	23	25	1740	23	51	2002
12	1248	674.802	2496.000	1073.601	21	44	1846	22	15	2002
13	1018	553.448	2036.000	1227.601	24	9	1872	24	52	2002
14	732	617.172	1464.000	598.000	20	49	1914	21	11	2002

Table 1.

The first three steps use the standard spatial analysis tools ALGEBRA, BUFFER and CLIP. Steps 4 and 5 use a special program, SCHOOL, which combines several spatial analysis techniques for efficiency.

SCHOOL sequentially numbers each school and determines its extent using recursive connectivity filling (PAINT) (Pavlidis 1982). The program tallies the number of pixels per school, from which area (m^2) can be computed (MEASURE). A minimum school size is specified to remove small schools (SLIVER), thus producing the final school mask. To determine fish volume density (kg/m^3) and school location (minimum/maximum ping and depth), the program performs an OVERLAY of the school mask on the echo data. Finally, EDGE is used to produce an outline of each school, from which perimeter can be computed (MEASURE).

With an accurately defined school outline and direct access to the complete acoustic data, additional school characteristics can easily be defined and measured.

The end product of the **school recognition** process is presented in Figure 4. Note that schools are outlined and carry a unique number. The results of **school analysis** are given in an ASCII flat file. At present it includes school identification number, depth, density, area, perimeter and school location. Table 1 shows a typical school analysis report.

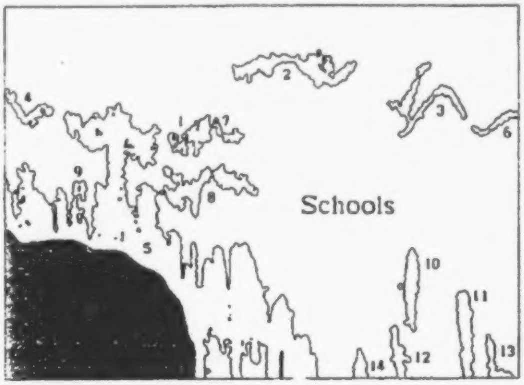

Figure 4. The SCHOOL program produces school outlines and labels. An OVERLAY on the echogram (Figure 1) will provide a clear picture of each school.

Discussion

This paper describes a prototype application for fisheries acoustics. The application is a complex, multi-step process. A GIS solution was chosen because of the spatial analysis tools it offered. Given the nature of the acoustic data, which were available as numeric matrices, raster-based processing was preferred.

This work has captured a new dimension in fisheries acoustic data processing. We are now able to analyze echograms in an objective manner. Processing proceeds one frame at a time and is no longer restricted to dealing with only one or two pings. Traditonal analyses often used a single pass, we use standard GIS tools and employ a modular approach that can be optimised to reach a particular objective. We believe that our fish school recognition and analysis procedure is the first of its kind.

It is anticipated that the application described in this paper, will enable improved estimates of fish populations, which, in turn, will permit more effective management of the fisheries resource. The application provides:

1. objective versus subjective school definition;
2. school specific analysis as opposed to previous average analysis methods; and
3. quantitative school characteristics. Not only visual properties such as size, periphery or depth, but exact measures of fish density and echo signal statistics can now be extracted.

Future enhancements to the application will include:

1. investigate species recognition procedures;
2. analysis of acoustic data by species; and
3. similar analyses for single fish echoes.

The application can also provide some insights into fish behaviour. We are now in a positon to monitor diurnal rockfish school structure and changes.

The case study is restricted to single beam echo sounding data. Future research will focus on the analysis of sonar and multi- beam fisheries acoustic data.

As it is unlikely that man's insatiable demand for natural resources, including those of the sea, will decrease, it is increasingly more important to manage these resources in the most effective manner possible. To do so requires the application of innovative tools.

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Concurrent Session 14

Environmental Issues - Climate Change

The Climate Model

Potential Use of GISs in Local Climate Warming Forest Research

Continental-scale Simulation of Potential Evapotranspiration for Historical and Projected Doubled Carbon Dioxide Climate Conditions

GIS 91

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Vancouver
British
Columbia
February 1991

Modeling the Impacts of Climatic Change on Terrestrial Ecosystems: A GIS Application

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State of the Environment Reporting
Environment Canada

Abstract

Climatic change over the next century could have a profound effect on the distribution and character of terrestrial ecosystems. Such changes would directly affect renewable resources such as forests, wildlife and water, which are inextricably linked to their environment. Using a GIS and a statistical package, climatological and ecological data were manipulated, integrated, analyzed and displayed producing a scenario of Canada's ecosystems under greenhouse warming. The research consisted of three parts: the first involved manipulating, analyzing, and mapping selected climate data; the second part dealt with the formulation of a classification model used to link the climate data to the ecological data; and the third part dealt with displaying and analyzing the results. The scenarios show not only changes in the areal extent of ecological regimes but also changes in their distribution and character.

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Potential Use of Geographic Information Systems in Local Climate Warming Forest Research

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Abstract

Most research studies that predict forest changes associated with climate warming have been conducted on global or regional scales. Research is now needed to predict forest changes that might occur within local management units. Digital elevation models can be used with raster- or vector-(TIN)-based geographic information systems for local climate warming research. Daily potential solar radiation can be computed for any slope. Therefore a radiation index can be computed for each forested slope by integrating daily potential solar radiation over the growing season; such an index could be used as a surrogate for climate. The GIS approach has several advantages. Stands can be efficiently selected to control for confounding factors other than radiation index such as parent material, elevation zone, stand density, etc.. The approach is empirical and can be used to test hypotheses generated by theoretical computer simulation models. Also, the approach can efficiently address research questions concerning the effects of climate warming on local forest change that would take decades to answer with controlled experimentation. However, most predictions of forest change due to climate warming will be speculative because of the fertilization and anti-transpiration effect of future increased atmospheric CO_2.

Introduction

The real potential for climate change during the next 10 to 100 years mandates a need to predict changes in forests associated with predicted climate warming. Increases in atmospheric carbon dioxide have been measured since 1958 (Gammon et al. 1985), with a resulting global warming of several degrees Celsius predicted within the next century (Graedel and Crutzen 1989, Schneider 1989). There may already be evidence of climate warming. The decade of the 1980's as a whole was two standard deviations hotter than the mean; six of the ten warmest years on record occured during this period (Kerr 1990). Research is desperately needed for rational forest management in the advent of climate warming.

Until now, most studies that predict forest changes associated with climate warming have been global or regional studies using computer simulation models (e.g., Davis and Botkin 1985, Pastor and Post 1988, Dale and Franklin 1989). However, much of our forest management occurs at the stand, watershed, or district level. What changes should forest managers expect at this scale if climate warming occurs? For example, will the mountain pine beetle (*Dendroctonus ponderosae*) decline in lodgepole (*Pinus contorta*) stands because of a less favorable (hotter) microclimate (Amman et al. 1988)? Or will the beetle become a serious forest management problem as lodgepole pine stands become drought-stressed with climate warming (Waring and

Pitman 1983)? Will the growth and yield of black spruce (*Picea mariana*) stands significantly increase with climate warming in the northern boreal area? Within a forest district, where are the hottest Douglas fir (*Pseudotsuga menziesii*) stands that might be planted to ponderosa pine? Where are marginal silver fir (*Abies amabilis*) stands that might be candidates for grand fir (*Abies grandis*) regeneration? The objective of this paper is to outline a GIS-based approach aimed at addressing such questions.

Predicting Changes Associated With Climate Warming

If we could model forest climate with a GIS, stands could be efficiently selected from 'hot', 'normal', and 'cool' areas for field-sampling. Confounding factors such as parent material, stand density, and elevation zone could easily controlled for with a GIS. Then, hypotheses about specific forest responses from climate warming could be tested. For example, Amman et al. (1988), have hypothesized that microclimate, rather than stand density, is a principal factor controlling mountain pine beetle infestations in lodgepole pine. A GIS might be used to select sample stands from the same parent material, elevation zone, and density class. These stands might then be ranked from the hottest to the coolest stands and examined for trends in mountain pine beetle density. If mountain pine beetle densities consistently increase across the gradient from cool to hot stands, one might expect beetle infestations to become more of a problem with climate warming.

Modeling Forest Climate With Radiation Indices

Potential daily solar radiation for any slope can be computed as a function of latitude, slope gradient, slope azimuth (aspect) and Julian day (Lee and Baumgartner 1966, Garnier and Ohmura 1968, Swift 1976, Kaufmann and Weatherred 1982, Harrington 1984, Flint and Childs 1987). Given a grid-based digital elevation model (DEM), triangulated irregular network (TIN), or stand polygon attributes of slope and aspect, potential daily solar radiation can be computed for each forest stand within a GIS. Each stand could then be assigned a radiation index (potential radiation relative to a level surface) by integrating daily potential radiation over the water-limited growing season. Stands could then be selected while controlling for other confounding factors such as density, parent material, elevation zone, species composition, etc.. After controlling for confounding factors, differences between selected stands would be assumed to be associated with differences in radiation indices. The approach is similar to comparing stands (in the northern hemisphere) from north-facing (cool) and south-facing (hot) slopes where each stand is similar in terms of parent material, density, elevation zone, species composition, etc..

Potential solar radiation has been used successfully in other research areas such as: optimizing orientation of solar panels (Klucher 1979); the prediction of the distribution of frozen soils (Zuzel et al. 1986); prediction of rock glacier development (Hassinger and Mayewski 1983); prediction of watershed runoff yield (Lee 1964); and vegetation ordination studies (Dargie 1984, Parker 1989). Hungerford et al. (1989) have used potential radiation in a model that extrapolates weather station data to to predict daily temperature and radiation at mountainous sites. This model has been used successfully to simulate forest evapotranspiration and photosynthesis (Running et al. 1987).

Radiation indices could be used as a climate surrogate with a GIS to answer many questions such as where are stands at the margins of a species distribution that are most susceptible to climate warming? Where are stands that are at the cool end of a species distribution and might be well buffered against detrimental effects of climate warming? What type of trends can be expected in insect and disease problems as climate warms?

Potential Problems

There are temporal problems witha radiation index approach. Potential solar radiation varies daily (Figure 1). What is the appropriate period to integrate radiation over - the entire year, the growing season, or the period of maximum drought? Potential radiation is the radiation on a slope assuming perfect atmospheric transmittance. Actual radiation will always be less than potential radiation; potential radiation indices should adjust for atmospheric transmittance (Bristow and Cambell 1984). East- and west-facing slopes receive the same amount of solar radiation; the difference between these sites is that east-facing slope

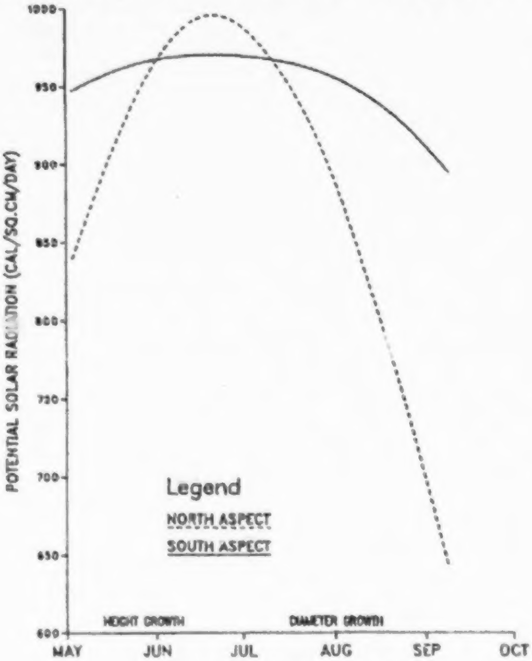

Figure 1. Potential solar raditaiton on 30% slopes at 38° north latitude.

receive daily radiation mostly before solar noon, while west-facing slopes receive daily radiation mostly after solar noon when plants are more likely to be under drought stress. This timing factor must be incorporated in a radiation index.

There are also technical problems that need to be addressed with using a GIS to compute radiation indices for forest stands. The computation of a radiation index for each stand would be computer intensive if many stands were included. It would be more efficient to develop look-up tables of radiation indices for different slopes and aspects rather than computing a radiation value for each individual forest stand.

Long-term climate warming will be associated with an increase in ambient carbon dioxide. Because of this increased carbon dioxide all models that predict changes due to climate warming but ignore the effects of increased carbon dioxide are speculative. For example, many computer simulation models have predicted a decrease in runoff due to climate warming. Revelle and Waggoner (1983), using computer simulation, suggested that watersheds in the western United States will suffer 40 to 75 percent *reductions* in stream flow due to climate warming. However, Idso and Brazel (1984), using the same computer analysis, but incorporating the antitranspirant effect of increased carbon dioxide, estimated that there would be an *increase* in stream flow with climate warming and the doubling of CO_2.

The effect of increased carbon dioxide on forest changes is poorly understood and yet may ameliorate some of the direct effects of a climate warming. Increased carbon dioxide may reduce the effects of water stress in some plant species. Tolley and Strain (1984) found that sweetgum (*Liquidambar styraciflua*) seedlings grown under water stress and elevated CO_2 conditions had final dry weights significantly greater than seedlings grown under well-watered, normal CO_2 conditions. Hurt and Wright (1976) found similar results with *Pinus attenuata* and *Pinus coulteri*.

Increased CO_2 may provide a 'fertilization effect' for some tree species at some elevation zones. The growth rate of subalpine trees in Nevada and California has been reported to exceed growth rates expected due to climatic trends but consistent with increased CO_2 concentrations (LaMarche et al. 1984).

Despite these problems, research is desperately needed for rational management of forests that may experience significant climate warming during the next rotation. Until now, much of the climate warming research has been on a global and regional level using theoretical computer simulation models. We need to begin empirical research on the local forest and stand level. GIS technology and radiation indices are tools that can be used to begin addressing the question: what trends can forest managers expect in our forests if the climate warms in the 1990's?

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A Continental-scale Simulation of Potential Evapotranspiration for Historical and Projected Doubled CO_2 Climate Conditions

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Abstract

Potential evapotranspiration was calculated over the continental United States for current climate conditions and for predicted conditions for a doubled CO_2 climate, using a turbulent transfer model presented by Marks (1988). The simulation was done over a grid of 138 650 geographically referenced points representing a digital elevation model (DEM) of the United States at 10 km spacing. Data for air temperature vapor pressure and wind speed at 10 m above the surface were corrected for topographic effects, and used to generate surfaces at the same 10 km resolution. These surfaces represent a long-term average monthly time-series for the period between 1948-88. Relative changes in these parameters were estimated from 2 times CO_2 scenarios from the GFDL and GISS GCMs. Potential evapotranspiration surfaces were calculated for both current and 2 times CO_2 conditions.

The potential evapotranspiration surface for current conditions shows evaporative stress maximized in the western United States in summer. This is significantly different from potential evapotranspiration estimated from Thornthwaite's (1948) temperature-regression method, which incorrectly shows evaporative stress maximized in the southeastern United States. Both GCMs predict increases in wind, temperature, and humidity. The GFDL model predicts drier, windier conditions than the GISS model, and shows potential evapotranspiration as very high in summer in the midwestern United States. The GISS model predicts moister but less windy conditions, and also shows a modest increase in potential evapotranspiration in the midwestern United States. This analysis illustrates the importance of physically based estimates of evaporative stress for climate change analysis. It also shows that it is possible to evaluate the sensitivity of surface processes, such as potential evapotranspiration at resolutions which are ecologically meaningful.

Concurrent Session 15

Education and Training

Technical GIS Training in the 90's.
A Retrospective, Introspective, and Prospective View

GIS Training and Education - the Need for a New Approach

Curriculum Materials for Advancing the Role of GIS in Education

GIS Implementation and Training Issues

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Technical GIS Training in the 90's A Retrospective, Introspective, and Prospective View.

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Abstract

Since 1981, the School of Natural Resources has delivered a program leading to a diploma designation of Geographic Information Systems Technician (GIST). The program has maintained close links with government and industry and has constantly adapted to the rapid changes in the GIS area. These developments, plus changes in governmental policy regarding education, have caused three different formats for delivering this curriculum to be used. This paper starts with a retrospective of the program though the early years, focusing on the main lessons learned that will still be of importance into the current decade. Given that historical perspective, an observation is made on where the GIS area is now and how training can reflect the current and near future reality. Lastly, observations on the basic philosophies and needs of any institution delivering GIS education are made. These include the need to cater to a variety of client disciplines and address a variety of different levels of application within the GIS field.

Introduction

The term GIS serves as a neat, but often indistinct, collective designation for a variety of activities and processes. These activities and processes find disciplinary residence in a number of diverse fields. Developments in computer science give us the raw material to create a GIS. Process-based disciplines such as surveying, mapping, and remote sensing provide the methods to apply the comput er to handling spatially related data. Finally, there are the application disciplines which use these systems and tend to influence the direction of new developments. When this disciplinary diversity is considered along with the emergent nature of GIS, we get a field which is changing rapidly in a number of different, and some might say uncoordinated, directions .

Any good educational curriculum, particularly one at the college level, should reflect the sum reality of the working environment, while at the same time providing sufficient skills and attitudes to allow the graduate to evaluate and potentially integrate new developments. Through the on-going use of advisory panels made up of private and public sector representatives, plus input from graduates and other interested groups, a program faculty should fine tune to ensure that their curriculum remains current. When GIS is considered in such an educational light, the diversity and developmental aspects mentioned make for an often difficult task. We are left with a sense of trying to pin down an elusive knowledge base and skill set.

It follows then, that an examination of a curriculum which has developed over several years serves not only as a pedagogical exercise for educators, but as a revealing survey for those who work in GIS in non-educational roles. A review of the reasoning behind why such a program is needed, how it is structured and the developing curriculum itself serves as a series of snapshots of the prevailing attitudes and beliefs of the various groups involved with GIS as a whole.

This paper will examine the development of the GIS program offered by Sir Sandford Fleming College (SSFC) at the School of Natural Resources in Lindsay, Ontario. Historical aspects will be examined mainly with the view to highlight what has been learned from these experiences: what has gone right, what has gone wrong, where has GIS been, where is it now, and where does it appear to be going. Given these observations, a number of predictions about the nature of GIS education in the nineties are made. It is hoped that these observations and those made by the other panel members will initiate meaningful discussion among those in attendance. To that end, this text runs the risk of being controversial in that it questions popular beliefs on what it is we call GIS. Please, provide some of the raw material for our ongoing curriculum review.

Part I: A Review of the Program at Sir Sandford Fleming College

The Early Years.

In the years leading up to 1980, individuals in a variety of disciplines that dealt with spatially related data were trying to gauge the impact of computers in their field. Some were making the most cursory of observations. Others, notably those in mapping, photogrammetry, and surveying, were becoming very aware of the role computers would play in their activities. It was a very unsettling period for many people. There was fear of the redundancy of skills and the loss of traditional quality in the mechanization of craft-based skills. Most of the fear arose out of a lack of focus in terms of where things were actually going. Pundits from various camps foretold of the new emerging computer based reality, some in glowing terms, others with less optimism. No matter what the position being taken by individual speakers, a summation of what was heard at the time made it apparent that something big was happening, or was about to happen, and things would never be quite the same again. It was also apparent that, if you did not acquire the skills or knowledge to be on 'the inside', you probably wouldn't survive. an all-pervasive air of expectation and apprehension seemed to fill these professions.

As 1980 came and went, these diverse visions and ideas seemed to coalesce around the term: Geographic Information Systems (GIS). While no one seemed to be able to define what GIS as an activity was, and where it fit into the overall picture, most seemed sure that it was the way of the future. It was against this backdrop that Sir Sandford Fleming College (SSFC) began to plan for a program that would address the issue of GIS and prepare a student to enter the workforce able to deal with the new technology. This program became known as the Geographic Information Systems Technician (GIST), and was one of the first of its kind to be offered in North America.

As was typical with much of the GIS activity of the time, the program grew out of the Cartographic Faculty at the school. SSFC had an established and generally well respected cartographic program that had, for the time, a fairly strong computer based component. It was felt that a new program was required to push the computer based skills to the limit within a technical program. It was interesting to note that at the time there was no consensus on the relationship between the existing cartography program and the new GIS program. Some felt that the GIS program would be an alternative to the cartography curriculum for those that were interested in computer-based work. That is to say, GIS really meant computer based cartography. Others felt that the new program was applicable to those that were interested in working in GIS but not necessarily with the mapping and cartographic aspects.

At the time the Federal government, under the mandate of the National Training act (NTA), was taking proposals for programs that would address skills shortages and provide direct 'high-tech' training to out-of-work individuals. The government offered very generous capital funding for start-up costs, and a unique system of government funding whereby the school providing the training would receive direct funding on a per-person per-day basis. Schools had to prove that there was a shortage of the skills they would train in, and create close liaisons with employer groups through advisory panels. The format for the programs would be a full trimestered, 52 week session with breaks for 'working world' holidays rather than the usual academic holidays. These parameters that the government defined would stand to be both boon and bane to the program.

Surveys of both private and government agencies showed that they were quite apprehensive of the shortage of people available to work in GIS. There was common consensus that GIS was to make a major impact on the spatial sciences in the coming years, and that training was vital. The exact nature of specific jobs in GIS was not always clear, with the emergent nature of the field being given as the usual reason for any vagueness in job description. Workstation operator was often given as a specific title, with this term being used to describe various tasks related to digitizing and interactive editing of graphic data.

Defining a curriculum at the time was somewhat difficult. Through the advisory panel of potential employers, the faculty attempted to balance a variety of subject areas. At the time, the term GIS was even more indistinct than it is now. There was no complete set of skills that could define the role of someone in GIS. again, the firmest component seemed to be the mapping related area. The rest became rather hard to pin down. From these discussions emerged a consensus that a workable curriculum should have primary focus in computer-based survey mapping. This would be supplemented with a variety of computer science issues examined in a GIS light. From this core of set of skills, it was hoped that graduates would be flexible enough to adapt into the different jobs that seemed to evolving.

Examination of the first curriculum showed courses in three different programming languages including assembler, along with courses in general data processing and operating systems making up the computer science side of the curriculum. These were juxtaposed against courses that dealt with surveying, photogrammetry, photo-interpretation, and basic mapping subjects. Combining the two areas were courses in graphic design, implemented on computer devices, and computer graphics peripherals, including digitizing and editing processes. The systems used in class, like most available at the time, tended to be oriented to map-based spatial data handling, and with limited attribute data processing ability.

The profile of the students who took the program showed two distinct groups. As part of the NTA mandate, students who entered the program all had to pass through Canada Manpower Centres. Some had backgrounds in fields that were beginning to use GIS, while many were simply out of work individuals who the government wanted to retrain for computer based jobs. Of those who had related skills, a high percentage came from cartographic backgrounds. Predictably, the employment placement of these individuals took two distinct paths.

Those who had related backgrounds found that the various computer courses complemented their skills and they had an easier time finding GIS related work. There was no distinct pattern for these individuals however. They did not go right into waiting GIS positions; they helped define them. Again, it was clear that GIS as an employment field had no defined pattern.

Those who did not have related backgrounds tended to be less successful in the program. They seemed to have a harder time connecting to the purposes behind what they were doing. What was of note was the number of these individuals who connected to computers in a general way and excelled at programming and computer graphics. Many of these individuals found employment with companies that were developing GIS technology. Others went on to further computer science studies.

A historical employment survey of both groups found that, of those reporting, the first classes had only 20% GIS related employment, with another 60% working in computer related work. As the program and the characteristics of the students entering the program changed, the GIS employment percentage grew. By 1987, these figures had changed to 80% of the graduates working in GIS and only 5% in computer positions.

The heavy mapping focus of this early curriculum brought it into conflict with the existing cartography program at SSFC, and created some confusion between the two programs among potential students and employers. As mentioned, the cartography program was developing its own computer based component in response to changes in technology and it was felt that the GIS program duplicated much of this effort yet left many cartographic principles poorly examined. This belief was further compounded by the widely held perception of the time that a GIS technician was simply the same thing as a computer mapping technician. Unfortunately, this view is still held by many today.

The Middle Years

As the program developed, the shift away from a computer mapping focus became evident. Newer faculty had experience in working in the emergent GIS field, notably in the management side of GIS rather than the mapping side. Courses that would be considered more directly GIS in nature were introduced. The theoretical side of GIS was examined through faculty lead discussion of various readings of indi vidual papers collected from a variety of proceedings and other sources. A standard textbook, or core of textbooks, simply did not exist. Interestingly, some of these original papers have been used in recent compendium texts (Peuquet and Marble, 1990, and Ripple, 1989). By the 1986 school year, the key course in each trimester was one dealing with GIS issues.

The systems used by the students expanded to include a variety of commercial systems. Unlike the earlier systems used, these would be considered to be more GIS oriented than computer assisted cartography products. In using these products, the concepts of why and what was being done with these systems was stressed rather than just the how. Student evaluations of the differences between these systems was integral to the curriculum. Independent projects that emphasized the analysis and data management aspects of GIS became more the norm.

The typical student of this period changed as well. a higher percentage of entrants came in with previous degrees, diplomas, or extensive related work experience. This translated into lower attrition rates within the program and higher placement rates for GIS related work after graduation.

Curtailment of Federal Funding

The program was maturing along with the GIS field when changes in federal government policy on education caused funding for NTA prog rams to be cut back dramatically. Each program was evaluated and funding discontinued if it was felt that the return to the government was not suitable. While many groups outside of the college, including several federal agencies, gave support to the program, a review by the federal government resulted in funding to the program being cut off, effectively curtailing the program in its original form. Part of the reasoning behind the move was the feeling by the department concerned that the needs of the GIS industry could be met by individuals who were receiving training in other areas, such as computer assisted drafting (CAD) and computer graphics.

The college was faced with abandoning GIS as a separate program and leaving the subject to be dealt with as part of cartography or other related areas. By this time, the cartography program was heavily digital, but the faculty from both programs felt that while the cartography department did a fine job dealing with the cartographic aspects of GIS, this was by no means a complete picture. There were whole other areas to be dealt with.

With the approval of the provincial government, the program was changed into a standard community college two year technician program, with normal entry coming directly out of high school, or the possibility of advanced entry from a post-secondary education background. While the change did allow for the continuation of the program, the level of funding was greatly reduced from the NTA days. Th is would have a negative effect on classroom hours, and capital (computer) equipment purchases and maintenance.

The Two year program

The first two-year class effectively started with the second semester of the program in January of 1989. All high school students entering the School of Natural Resources in September take a common semester of natural resource related courses, and start an area of specialization in January. A small group of students directly out of high school elected to take GIS, and these were supplemented by direct entry students, mostly with natural resources diplomas, or university degree backgrounds.

It soon became apparent that those directly out of high school were having difficulty connecting to the issues being discussed in the program. It the early years the GIS issues where not that sophisticated, so 'outsiders' could still follow what was going on. Now, with advances in the technology being used and the more formalized curriculum, those who had no concept of geographic issues simply could not keep up. By the end of semester three, there was only one non-related background student in the course, and that person did not complete the program. Clearly, the idea of offering a fairly intensive GIS curriculum to someone with no appreciation of an application to use it in was no longer going to work. To be successful, a student needed a primary application skill first. The GIS program would be a supplemental method of applying that primary skill.

The other major problem with the two-year format was the time frame. With integration of the program into the normal school year, it now meant that an advanced standing candidate out of university was looking at a sixteen month period from starting the program in January until completion in the April of the following year. This was simply too long to wait, and while interest remained high, registrations fell.

The GIS Applications Specialist Program

To address these problems, it was decided to move to a new approach. One that recognized the advanced and diverse background of the potential candidates and allowed for a reasonable time frame for completion of the program. With the provincial government now supporting life-long education, it became much easier to gain approval of a post-diploma specialist program that would only be offered to people who had post secondary education, with a two year technical diploma being the minimum. The content would be streamlined to allow for completion of the program in one academic year, September to May.

The old GIS program was evaluated for components that would become part of the new curriculum. Input was sought from various advisory groups. Developments in GIS technology and practice were examined. Things that were happening in GIS education were looked at, including the development of the GIS curriculum from the US based NCGIA. There would be some compromises made, but a core curriculum was developed that would allow an individual to gain a junior position in GIS and use their education as a guide in their ongoing, hands-on development in GIS. The new curriculum starts with a core of three courses in GIS: introduction, technical issues, and applications. These are loosely based on the NCGIA curriculum available through the University of California at Santa Barbara. Supporting this core are courses in data management, georeferencing, remote sensing, computer studies and communicating geographic information , each of which is taken from a GIS perspective. There is also a major independent project to round out the program.

Courses were defined to allow for exploration in what were becoming the basic building blocks of GIS. Integration of skills between the courses and referencing back to wider GIS issues is emphasized. The ability of the graduate to independently find solutions to new problems and integrate new ideas and processes into their personal skill-set was paramount.

Many of the ideas about GIS education that follow have come out of this review and curriculum development process. We have built on what worked in the past. So far the feedback has been good, but only time will tell if this is the right track. One thing is clear: GIS education will constantly change as the discipline changes. It is important to keep a balanced view of the field in order to create a credible program.

Part II: Observations on GIS Education in the 'Nineties

Disciplinary Diversity

GIS education must reflect the fact that individuals who require training will come from a variety of backgrounds. The requirements of these individuals will vary. Why they are interested in GIS, and what they want out of education will be different depending on their level of education, work experience and the discipline they come from.

The first logical breakdown of the different disciplines around GIS is what I will refer to as internal or external users. Internal user groups are those whose primary purpose is in the operational aspects of GIS. They do what they do to make GIS work. Such groups would include the analysts and programmers who create the systems, the surveying, photogrammetry, and mapping staff that build the original topographic database, cartographers who work with

GIS to create map products for a variety of other users, and remote sensing personnel who work with a variety of digital data. External users are those whose primary purpose is not related to GIS but to so me other activity. They need GIS to do something else. These are the application based users in natural resources, social sciences, and the list grows daily. The way these two groups view GIS is quite different. Even within each group there are a number of different needs. GIS education must acknowledge these differences.

This is not to say that all technical aspects of GIS should be hidden from application type users. The basic issues must always be carried forward into working situations. How these basics transform into everyday processes will vary, and this is where the difficulty in staffing comes in. The broader the background of the collective faculty, the more students they will be able to relate to. This must be balanced against some kind of individual specialization that yields real experience. The key is to have a faculty that integrates well, each being aware of each others interests and abilities. Courses must fit together and not be fragmented into the personal divergent interests of individual faculty members. It is also of value if specialized individuals in disciplines surrounding GIS can be accessed to provide leadership on specific interests of individual students. This is where a focused campus like the School of Natural Resources is very beneficial.

The Activities That Are GIS

The types of positions that graduates will find themselves employed in will vary greatly. Early GIS graduates tended to work in basic mapping or GIS system development. That profile has changed dramatically. The background application discipline of the individual plays a much bigger role in GIS based job selection.

We must accept that GIS is not just the creation of maps. While GIS capable basic mapping must be completed before GIS activity can usually begin, there is much more to GIS than the graphic components. The collection of attribute data and what happens to the data once collected is just as important as the processes surrounding the graphic or map data. Unfortunately, the dense dataset that is the spatial data component of the GIS is often so complex and large that the only way we can quickly visualize it is through maps, so maps tend to become an inevitable component of GIS. As mentioned in Part One, the historical roots of GIS in survey mapping and related fields has ensured that these components of GIS were well represented in early programs.

The other processes in GIS must not be overlooked in GIS education. The sorts of analysis that go into creating a forest management plan may find ultimate communication in a map, but should not be generated through maps. Activities like this require skills beside those of the mapper. Too often this is forgotten in the rush to embrace the new technology. The ability to understand the capability of a GIS to process, manage, and analyse the data is key to total GIS education.

Primacy of GIS

All the diverse users of GIS must come to accept that GIS is a tool within the various fields that are now using it. Too often, we think of GIS as a concept that becomes more important than the things we are trying to do with it. GIS as a discipline lies at the edge of a variety of other areas, overlapping many but really being too diverse and scattered to become a distinct discipline. For example, in the mid-eighties it was not uncommon to hear that there would no more need for cartographers since GIS would replace them. G IS simply changed the way they function, and allowed the cartographer to consider less the more mundane aspects of map production, and key in on the skills that made them unique, such as visual design and communication, and map structure. This analogy holds for other fields as well.

To forget the primacy of the application over that of GIS the tool often results in the alienation of individuals within various organizations, who come to fear GIS and not to trust those who work with it. Such an attitude creates problems for those that intend to study GIS and find employment using this technology. For an employer to state that they want a GIS person is simply too unclear a position. The growth of GIS will take on new strength when potential employers start working from the perspective that they may want a GIS capable surveyor, biologist, cartographer, etc., rather than just someone with GIS skills who can just be thrown at a problem.

Generic Skills

Because of the diversity of application, it is not justifiable to teach specific skills that apply to one aspect or system within GIS. Building block skills and understanding, as opposed to specific system knowledge, is absolutely necessary. It is not uncommon for faculty teaching GIS to be questioned by someone who has interviewed a graduate for a job position and found them lacking in a certain skill or process. If the comment points to a gap in our curriculum, then changes are likely, but too often the criticism is over a small point that applies to the particular area of GIS that the individual's organization is involved in or the specific system they are using.

As opposed to showing a student a whole range of commands to be simply memorized, it is far better to teach through a process that first allows the student to establish and understand what task is needed in a particular instance and why, and then assists the student in finding out how a particular system implements that task. Further examination of other GIS systems and analyzing the differences and similarities between them develops a more adaptable individual. Rather than having an employee who happens to know how to do task X on system A, it is surely better to have someone who would know what task was needed in the first place and who could independently figure out how the system implements that task.

Work-based Development

We must accept that any training scheme will only produce a basic set of skills and will not create an overnight GIS expert. The majority of learning will come through on the job experience. It is unrealistic to expect an individual coming out of a short GIS program to be able to consult on the installation of a GIS or some similar task. If anyone who works in GIS examines their own personal skill set, they will soon realize that it was developed over time and through exploring a myriad of issues that slowly developed into a more complete understanding of the subject. Much of what happens in GIS is very complex, and is rarely understood the first time around.

System specific training must happen at this level. The number of systems available today makes it impossible for a generic school to focus on all systems. A good school will key in on those systems that represent the major 'styles' of GIS development in as few systems as possible, and teach generic skills through the varied mechanics of these systems. If this is considered, a student will not become a high-end user of any one particular system. This will be achieved only through ongoing experience with the system, possibly supplemented by short courses in specific aspects of the system provided by the vendor or other agency. Yet, many agencies still expect a one-year student to be an advanced user in one system. While certain systems dominate in terms of pure numbers, there are still many systems in use, and to ask a student to invest a lot of time into one niche of the market is unfair and unrealistic. Even within a single system, the rapidity of upgrades makes specific skills redundant.

Simpler Systems and Educational Overhead

One of the main problems for GIS educators has always been the high cost of equipment and software. Not always apparent to those setting up new programs is the ongoing expense of maintenance contracts and upgrades. With creative work, special capital funding can be acquired for initial purchases of hardware and systems, but the maintenance contracts on hardware and software can easily become crippling to a small department.

Microcomputer-based systems have gone a long way to reducing the purchase price of hardware, and usually do not require service contracts. This is the real, but not always apparent, advantage to going to microcomputers. True, there is a loss in capability, but given the power of new systems, and the seminal nature of the education delivered, this is not a major problem.

The remaining problem is software contracts. With three popular micro-based systems running on single machines, the annual service contract cost can pass ten thousand dollars. While there has been some improvement, it is clear that software vendors still view education as a commercial enterprise. Given the current level of funding available to college and undergraduate education, such costs are almost unbearable. Newer, more creative, methods of software acquisition are needed.

Systems aimed at the educational sector are one solution. Products such as OS map, from the Ohio State University, Columbus, Ohio, and Idrisi, from Clark University, Worcester, Mass., have evolved into powerful systems in their own right, and are available at minimal cost. Ignoring the advantage of cost, systems such as these provide two advantages. They allow for a low stress introduction to GIS, and are evolving into powerful systems that illustrate some sophisticated aspects of GIS quite nicely.

In the increasingly competitive GIS market, some vendors are now looking at their return being realized in terms of number of people exposed to their systems, and are willing to give up the maintenance aspects of software licensing, allowing the school to pay for direct service or upgrades at cost.

Assuming a mechanism exists for external funding, schools can raise support monies through external projects or short courses. Experience has shown that external projects do not always mesh with undergraduate educational activity. Problems of scheduling, capability of the students, teaching loads of the faculty involved, and travel can quickly interfere with the operation of the project. One bad experience can sour relations very quickly. This sort of work is best left to post-graduate university students. Short courses can work well, although there is a problem of timing. During the traditional school year, the GIS facilities of a typical school are stretched beyond breaking, and the secondment of those facilities at mid-term, even at night, is almost impossible. This leaves the May to August time period available in most schools. This period appears to be popular with working individuals and academics alike. The ability of staff members to recover from post-year burnout and marketing are the major parameters here.

Time Effective Training

The amount of time a person can invest in education is minimal. GIS training must happen over a relatively short time period. In contrast to this need is the stated complexity of the skillset that is GIS. GIS understanding does not happen in a week. It is unrealistic to expect a person to attend a one-week Introduction to 'System A' course and expect them to work in GIS. On the other hand, it is naive to expect them to attend school for two years to add to an existing skillset. Clearly, time frames will have to be adjusted to suit a variety of users.

For someone who works in an area where GIS has become established and is acquiring skills on an ad hoc basis, short courses are ideal to speed through a variety of processes that would take inordinate amounts of time to absorb independently. These packets of information can be explored on the job, while developing other skills. Such a person may need basic computer familiarity training first, but our observations have been that this type of person picks this information up quickly. Organizations will have to be flexible in supporting these activities or, alternatively, allow for leave to attend longer courses.

The program at SSFC is designed for the individual who is not working with GIS at all, but has a background in a field that is, or will be, using GIS. As mentioned, the focus is to give as many 'building-block' skills and experiences as possible in a short period of time to provide a platform for the individual's intelligent growth path in GIS. While there is a great need for this type of education right now, it will drop off as integration of GIS training happens in general education.

It has been our experience that just education in GIS by itself is not usually very effective at this level. There has to be an application aspect to the educational package. Normal post-secondary diplomas or undergraduate programs in GIS do not look very feasible at this time. University post-graduate programs will offer the opportunity for established individuals to do research into the advanced topics surrounding GIS. The appealing part of this type of work is that the development can be based on the different core components of GIS such as computer science or remote sensing, or it can be conducted purely from an application perspective.

Integration of GIS Education Into Existing Curricula

Ultimately, the future of GIS education lies in the integration of GIS principles into the existing educational structure that provides for the initial skills of individuals. At the post-secondary level, this does not mean adding a GIS course to an existing program, although this may be the first step. To work effectively, it means incorporating GIS components into the curriculum as integral parts of all the different courses that could use GIS. For example, a forestry management course could be based on using a GIS system to explore the various issues related to management. While there would be changes required, the payoff would come in the increased abilities of the students to model various processes, rather than the static examination of conceptual models. Making this model work goes back to the issue raised in accepting that GIS is a basic tool for use by various disciplines, rather than a primary discipline itself. Accepting GIS into the curriculum does not mean that GIS personnel take over the program of studies, and those who did work in the program are displaced. The primacy of the application and the student's understanding of the basic principles involved in it must be upheld. There is resistance to this by faculty that do not wish to change, or acquire new skills, but just as industry is changing, so must education.

An example of this integration is in the cartographic program at SSFC. Here, a slow integration of computer courses has lead to a program that teaches a primary skill to high school students, yet does it in ways that make the computer just another method of creating maps. The program graduates GIS capable cartographers. The cartographic skills of these individuals is what defines their profession, not their GIS skills.

Conclusions

GIS education has gone through a variety of changes over the last decade. These changes have reflected the maturing of GIS practice in industry and government. Over the years it has become clear that GIS education cannot function alone. It must be coupled with an application skill, be it internal to GIS activity or as a user of GIS. The skills required for an individual to work in GIS are varied and often very complex, almost subtle in nature. This creates difficulty in defining a good all-purpose curriculum.

The acceptance of GIS as a component of a wider skill set means that the candidates for GIS upgrading education will come from wider backgrounds creating potential staffing problems. at the other end of the process, the types of jobs these individuals will be going into will continue to become more varied.

GIS education will have to become more flexible in terms of time of delivery. Given the crisis in educational funding for post-secondary education, this problem is not about to go away. The funding problems create headaches for schools trying to keep current and up-to-date systems available to students. Different relationships between systems developers and educational institutions are needed, and have started to happen.

GIS education is in a transitional state. While there is a dramatic need for upgrading education for individuals lacking GIS skills right now, this need will diminish as GIS training become integrated into a wide variety of primary application curricula. While those in between working positions find it easier to commit to longer-term programs, those who hold working positions cannot, and more flexible methods of training are needed for these individuals both within their working environment and at educational institutions.

Just as there are no fixed solutions in GIS, there is no perfect GIS educational model. What is needed is a sensitive, sensible, and flexible approach to education. One that effectively evaluates the GIS 'market' and responds to it in ways that reflect the needs of potential students. Once anyone feels they have got it right and can sit back for a while, they are probably in trouble.

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GIS Training and Education - The Need for a New Approach

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Abstract

One of the most important components of any GIS implementation is the training and education of the user group. Despite the importance of this component, neither the vendors, educational institutions, nor the user community are adequately meeting the training and educational requirements to ensure efficient and cost effective use of GIS.

GIS training is frequently the most neglected aspect of an implementation plan. The importance of providing sufficient training and the risks of not doing so are often not understood well enough by project managers. If GIS implementation and integration are to succeed, these attitudes and misconceptions must change.

Using the B.C. Ministry of Forests District GIS initiative as a case study, this paper will examine some of the common training pitfalls, how to establish an effective training strategy and accurate budget, as well as addressing some of the current constraints to fulfilling educational and training requirements.

Introduction

One of the most important components of any successful GIS implementation is the presence of well-educated and trained staff. Because GIS impacts virtually every level of an organization, this group needs to have membership which includes senior management through to administrative support, each of whom must be educated or trained in a relevant way. Despite the fact that education and training are such an integral part of a successful implementation, they are frequently the most neglected. The 'real' costs are often not calculated and the risks of inadequate training are often not acknowledged or known. Furthermore, there is a prevalent attitude that training is too costly, too time-consuming and too risky.

In order for GIS to be successfully introduced and then integrated into an organization, these attitudes and ideas about education and training must be abandoned and a new approach adopted. This new approach is straightforward: education and training must be recognized and accepted as being one of the cornerstones for any GIS implementation. For without both a philosophical and, especially, a fiscal commitment to GIS education and training programs, the acquisition of this technology, regardless of the system's sophistication or power, can be a very expensive but futile exercise.

Education is the primary requirement and is needed during the initial stages to give the decision makers the knowledge to evaluate whether certain actions or decisions concerning GIS are desirable. More detailed information is then required, in the form of training, to enable both the decision makers and operators to improve their ability to use GIS on the job in a way which will help fulfil organizational goals.

Although this all sounds like common sense, which hardly warrants several pages of discussion, it is worthwhile to note that saying education and training are important is much easier than identifying and calculating the effort, resources, commitment and expense necessary to create and then deliver the programs themselves. Using the Ministry of Forests as a case study, this paper will examine some of the reasons why transforming the idea of GIS education and training into a reality became such a demanding task. The need for training and education will also be explored as well as prevalent attitudes towards training. In addition, this paper will discuss building a case for an education and training program, how to identify associated costs, benefits and risks and will provide recommendations for establishing an effective education and training program.

The Ministry Case Study

The provincial Ministry of Forests is organized into 15 branches, 6 Regional and 43 District offices. Employees number in the thousands and those directly impacted by GIS will eventually number in the hundreds. In accordance with the Ministry of Forests Act, all of these organizational entities are responsible for one objective: to manage, protect, conserve and plan the use of the forest and range resources of the Crown. The instrument chosen to enhance the ability of various levels of the Ministry to meet forest management requirements, especially the complexities of integrated resource management, was GIS. Working toward this goal, the 6 Regional offices received GIS in 1985 and the Ministry proposed to supply GIS technology to all 43 District offices by 1992.

Background

Even though the transfer to a digital database began over a decade ago, it was not until the early eighties that the analytical capabilities of GIS began to surpass the relatively straightforward requirements for producing cartographically correct digital maps. The 6 regional offices were introduced to GIS in 1985. The implementation strategy was simple: hardware, software and user manuals were sent to 6 locations across the province. A small support group was formed in headquarters to assist users; however, a formal education and training program was neither considered nor delivered. Thus, the GIS users at regional offices were almost entirely self-taught. Anyone familiar with the GIS of the early eighties will recall that the systems were definitely not designed for self-instruction. As a result, it took staff longer to gain sufficient skills to operate the GIS to the point where any tangible benefits from it's implementation could even begin to be recognized.

In 1989, under the direction of two Branches of the Ministry, GIS was delivered to 21 District offices. Previous experience had demonstrated that our delivery approach should be changed, so an implementation project team was organized. The plan was much more sophisticated this time, involving implementation committees and sub-committees, action plans, computerized time-lines, installation schedules and support strategies. But still the education and training programs required to meet organizational goals and objectives for GIS remained poorly defined. Technical and some professional staff were receiving training, but line supervisors and senior management did not understand why the training program was so involved or why delivery of the program was going to take so long. An education program for supervisors and managers was recommended but was not implemented until almost a year after the project had commenced.

Current Situation

Following a third party review of the District GIS implementation in November 1989, in which several concerns were identified, a decision to temporarily suspend the implementation was made in January 1990. Work is in progress to resolve some of the problems facing the implementation, including those of education and training.

The Need For Education

GIS is very dynamic and has the potential of impacting virtually every part of an organization. From effecting senior management decision-making processes to staffing and job classification issues, to office furniture acquisition and layout, GIS implementation and use brings about considerable organizational change. This technology changes the way people do their jobs and often their sense of self-esteem and belief in their value to the organization.

If these changes are ignored, staff will go elsewhere. Therefore, it is important that an education program for managerial and supervisory staff be in place prior to GIS acquisition so that these staff are equipped to administer the changes brought about by GIS implementation long before they occur. Additionally, early education will assist managers to make informed decisions about the myriad issues related to this technology (Chock, 1990).

To properly manage a GIS initiative the costs, benefits and risks must be calculated, or at the very least, estimated. Even a rough idea is better than no idea at all. In our own case, these costs, benefits and risks were not identified soon enough in the project and, justifiably, concerns began to increase as costs began to mount. We neglected to identify the real costs up front so that management knew what the fiscal commitment to the project was going to entail. What we also neglected to do was ensure middle, senior and executive management had sufficient knowledge of the training program at the early stages. For without an adequate commitment from management in the early planning states, a corporate implementation of GIS will be at best difficult and at worst, doomed.

Consequently, the education of senior levels of management should be the first priority of any GIS initiative. Even though it is a difficult task to keep up-to-date with the complex and ever-changing technology of GIS, it is mandatory for managers in particular to do so if the decision has been made to implement and use this technology.

The education provided for management staff must focus on how GIS impacts management as well as what is required by other employees to achieve GIS related goals. For it is only with management approval that sub-management levels will obtain the resources they require to fulfil what is being asked of them. The appropriate decisions and approvals can only be made by well-informed managers.

The budget for the education program for Ministry managerial and supervisory staff was $25,000 for the 1990-91 fiscal year. This budget allows for the development and delivery of a limited number of 4-hour informational seminars on GIS issues. This is clearly not enough time to equip managers with the knowledge they require to administer the GIS issues which will confront them, therefore, opportunities for a more comprehensive program will have to be examined.

Once an education program for managers and supervisors has been developed, the education of professional and technical staff must be addressed. Although the education of this staff group has a different focus, it is essential that they too be made aware of the organizational impacts of GIS, the extent of training required, the reasons for the training and the expectations of managers and supervisors once the training is concluded.

Training as a Critical Component of Implementation

Figure 1 illustrates some, although not all, of the critical components of a GIS installation: data, trained staff, GIS and outputs. Although other components are crucial, those which receive the most attention tend to be the hardware, software and data issues. However, training and education should be regarded as equally important, for without them, GIS implementation will be endangered. Like links in a chain, each component is as critical as the next and weakness in one weakens the whole.

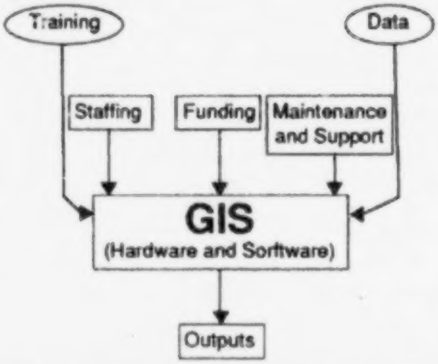


Figure 1. Critical Components of a GIS Implementalton

After deciding what the GIS is required for, the next important step is accumulating the data from which outputs will be produced. This means data that is in sufficient quantity, is well-structured, accurate and at a resolution which ensures the types of decisions based on this data will be credible.

The main objective of using a GIS is to produce required outputs. Whether these are in the form of reports, maps or decisions about how a resource is to be managed or used is incidental. For this discussion, the particular brand of GIS selected is also of little consequence.

Even after ensuring that your data is adequate, a GIS sufficient for your needs has been selected, and your outputs are defined, it will be very difficult to produce these outputs without trained staff available to perform the processing and analysis.

An analogy to illustrate the co-dependency of these components would be that of travelling by automobile. The outputs are the destination. The destination for our Ministry's GIS initiative is more effective integrated resource management. The engine driving us towards that destination is GIS. But without a balanced input of gas and oil, the training and data, the engine will not get us where we want to go.

Attitude as an Indicator

The main sources of information on GIS training issues are references dealing with GIS implementation as a whole. However, a review of the literature shows that there is very little discussion of education and training needs.

While there is a multitude of articles or chapters that deal with the subject of implementation, database design, or hardware and software selection, the area of training is usually relegated to only a few sentences or paragraphs. This may very well be a indicator of the value placed upon training and education issues.

The attitude of management towards training can also be an indicator of the need to educate managers themselves. For example, the most commonly heard comment with respect to training during the District GIS implementation was 'We'll become a training ground for staff, who, once trained, will leave to work elsewhere.' This will indeed happen if:

- new skills are not incorporated into existing job duties;
- there is no career path to follow once new skills have been acquired;
- salaries are not commensurate with now expanded knowledge and abilities; and
- management and supervisory staff do not recognize or respond to this improved work force.

If this is the attitude of management to new or newly skilled employees, employers are not just risking high staff turnover, they are actively encouraging it. Therefore, managers and line supervisors must be educated in areas such as change management and must especially be made aware of what changes GIS will introduce. How are managers and supervisors to deal with staff who have undergone significant technological and educational changes? Unfortunately, the most common reaction is frustration; frustration that although staff have spent several days or weeks away on training, the full potential of GIS is not being realized and other work is not getting done. To avoid this frustration, it is crucial that managers understand the complexity of these systems and the length of time it takes to master their use.

Building the Case for Education and Training

There is a very ordinary reason for providing staff training and education in conjunction with the introduction of GIS technology. Education is to inform staff of what the new tasks are and why it is important to the organization that these tasks get done. Training enables staff to use these new tools or methodologies to perform these tasks properly. As was the case several years ago, geographical information systems are still not candidates for self-instruction. Therefore, calculating the risks of not providing formal training and education is simple: the staff who are responsible for getting the job done are unable to do so.

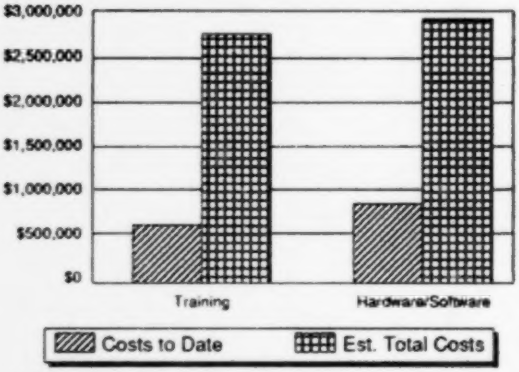
Obviously, with this as the consequence, the necessity for training and education must be accepted as an integral part of the project and the organization must be prepared to approve and bear the associated costs before the project begins.

It is customarily very difficult to identify the tangible benefits of training, which is perhaps another reason why training is not always handled appropriately. For example, what is the dollar value return of staff knowing how to create digital elevation models? Perhaps more to the point, what is the value lost without such expertise? In building a solid case for GIS training and education, it is worthwhile to assess the cost of certain tasks not being done or being done improperly.

Identifying the Costs

There are numerous models and formulae which can be used to calculate or estimate the costs associated with education and training programs. The criteria for selecting any particular formula is that it takes into account **all** of the cost-accruing factors, such as needs analysis, instructional design, course specialization, facility and equipment rental, instructors fees, staff salaries, including benefit package percentages, travel and accommodation expenses as well as salaried time or contractor's fees for evaluation and validation. Frequently, the only costs itemized are tuition fees and this presents a very misleading picture of the total price the organization will ultimately pay.

The cost of hardware and software acquisition for the District GIS implementation will be approximately $2.9 million. The cost of the technical training program is calculated at approximately $2.8 million, almost equal to the hardware/software acquisition expenditure. In other instances, the costs of training programs can be twice that of hardware and software (Sandquist, 1990). Since training in many cases can be as, or more, expensive than other implementation costs, it is necessary that training be given the same profile as other implementation issues.



*All figures are approximate values

Figure 2. Training versus Hard/Software Costs

Clearly, training budgets will continue to place a strain on the financial resources of the Ministry. But what is the impact on the forest resource itself if the budget is not allocated to train staff to enhance their ability to manage this resource? And what is the cost of having inadequately trained staff operate $2.9 million dollars worth of hardware and software?

Each organization must assess the cost, both in economic and social terms, of not fully training their staff in how to use this technology to its full potential. The question soon becomes not whether you can afford to support a GIS implementation with a full scale training program but whether you can afford not to (Sandquist, 1990).

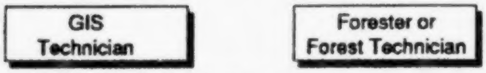
Establishing Effective Training Programs

As can be seen, training and education costs are not trivial amounts, so it is imperative that these programs be well designed and managed. A well designed training program will address the following:

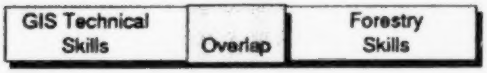
- who will be trained;
- content of the training program;
- who will deliver the training;
- evaluation; and
- validation.

Who To Train?

Intially, a needs analysis should be conducted to determine the qualifications for selection of GIS staff, what GIS users are expected to produce with this technology and what specific training is required to enable them to accomplish these tasks. It is important to note that the selection of staff to fill GIS positions will have a direct influence on the design of the training program. Figure 3 illustrates three possible staffing options for the Ministry. Each option would necessitate three distinct training approaches.



Option 1
Two seperate job functions.



Option 2
Two seperate job functions that interact, co-ordinate and share skills and knowledge.

GIS Forester
or
GIS Forest
Technician

Option 3
One job funcion that covers both the needed skill areas.

Figure 3. GIS Staffing/Training Options

Course Content

Regardless of the staff selected to use the GIS, if an organization's expectations exceed the skill level obtained from the training program, then one or the other must change. The program must also incorporate several levels of training sophistication if numerous staff are responsible for different components of a GIS analysis, such as data capture, spatial analysis, programming, planning scenarios or overall project management.

The training matrix shown in Figure 4 illustrates the diversity of training needs based on staff responsibilities. As these responsibilities change, as they frequently will, so too must the extent of training identified for each staff member.

The Ministry found it advantageous to have specialized course material prepared so that instruction matched more closely with on-the-job tasks. Full- sized Ministry data sets were used as were forest management examples and scenarios. Although course specialization of this kind can be costly, it can benefit the organization in two ways: staff will have a more realistic view of the time requirements and complexity of GIS manipulations and they will also become more familiar with the data they will routinely use in their own work environments.

Job Function

Training Required	Decision Makers	Output Users	Project Designer	GIS Analyst	GIS Super.	GIS Op.
Intro Seminar	x	x	x	x	x	x
GIS Concepts	x	x	x	x	x	x
Basic Computer				x		x
*System Mngment.					x	x
Graphics						x
Inv. Data Management			x			x
Inv. Update *Problem Tracking			x	x	x	x
Attribute Processing			x	x		x
GIS Analysis				x		x
Database Management		x	x	x	x	x
Project Management			x	x	x	x
DTMs				x		x
Utilities *File Translations			x	x		x
Custom Applicaitons		x	x	x	x	x

Figure 4. GIS Training Matrix

Who Delivers The Training?

Equally important to the content and duration of training is identifying who delivers the training. The current trend is to rely on the vendors because of the complexities of their individual software packages. This is not always the most advantageous approach as software designers are not normally professional educators.

The intimate knowledge of geographic information system technology does not automatically imply an inherent ability to teach. Just as the GIS client group has been slow to appreciate the importance of training, so too have the vendors in establishing training departments staffed with professional educators and instructors. In addition to selling program software, vendors should be intent on continuing to provide training services. These must be provided by staff with the appropriate instructional credentials and skills.

Evaluation

Evaluations must be conducted at every training session. This is the only way to determine if you are receiving the best value for the money spent on training. Evaluations should be used to gauge if the training follows an established curriculum and determine if the training is still relevant to on-the-job requirements.

Carnevale and Schulz (1990) recently reported that approximately 50% of all training programs in the U.S. are not evaluated. If evaluation analyses are not conducted, it is impossible to assess the effectiveness of training programs, let alone make recommendations for necessary changes. An extensive evaluation program was established for the District GIS project to assess whether the customized training met Ministry needs. This consisted of over 350 pages of evaluation documentation from 40 staff members following approximately 7000 person-hours of instruction.

As a result of this evaluation, significant changes were made to the course content as a direct result of input from students receiving the training. The end result was that the training delivered was able to more closely meet the needs of the participants as well as those of the Ministry.

Validation

Following evaluation, validation of the skills learned during training must take place back at the job site. This involves measuring the performance of staff who should now be doing the tasks for which they were trained. If they are not, then the organization may not be managing trained staff effectively and the organization's utilization of these staff members must be adjusted.

Each part of an effective training program must be properly managed, from initiation to conclusion, and the responsibility for this management must be delegated to specific individuals or groups of individuals who are convinced of its importance. In addition to this new responsibility, these staff must also be given sufficient time and resources, apart from those required by their regular job duties, to be able to dedicate themselves to the training program.

To properly manage each of the numerous components of the training package, it is important to have the right kind of people involved.

Unlike data or hardware/software issues, training involves human beings and, therefore, cannot be managed in the same way. Many times the individuals involved in GIS implementation do not have the necessary personnel management skills to establish and oversee effective education and training programs.

Once again, like the links in a chain, the overall strength of the training program is dependent on the strength of each individual element.

Conclusions

To help make GIS implementations, especially in large organizations, less problematical, a new approach to education and training is needed. This approach requires a recognition of the importance of GIS education and training and a commitment to establish corporate-wide GIS education and training programs. Following this, all levels of the organization, especially middle and senior management, must receive some degree of GIS education and training in order that all who will impacted by the implementation will be equipped to properly manage and use this technology.

The training function must be recognized and regarded as equally important as other issues, including database design or hardware/software selection. The necessary resources must be dedicated to establishing and maintaining education and training programs by decision-makers who are convinced of and committed to the role that these programs play.

Recommendations

In an effort to help establish more effective training and education programs, the following recommendations are given:

- once the decision to implement GIS has been made, assign the responsibility of formulating and managing the education and training components of the implementation to a specific group;
- define a comprehensive education and training strategy to determine who will be trained, what will they be trained for and why;
- calculate cost estimates for the development and delivery of corporate-wide GIS education and training programs. Ensure that estimates reflect the **total** costs;
- determine if a budget can be supplied to cover the total cost estimates;
- approach management and supervisory staff to determine the extent of support which exists for training and education in general and GIS in particular. If support is weak, efforts should be directed to the education of this staff group prior to any further implementation activities;
- request, and be prepared to finance, specialized rather than generic training to meet specific organizational needs, if necessary;
- evaluate and validate training; and
- consider a pilot implementation, if your organization is large, to 'work out the bugs' before full-scale implementation begins.

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Curriculum Materials for Advancing the Role of GIS in Education

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Abstract

It is a common misconception that, in order to be legitimately involved in GIS, one must have served some time at 'the bleeding edge' of GIS development. In reality, GIS is a technology which can and must penetrate through traditional barriers to technological diffusion. Certainly, a fundamental grounding in geography or surveying and mathematics provides a student with some distinct advantages , but there is nothing magical or inaccessible about the background they provide. The Canadian Centre for GIS in Education has produced a Curriculum Development Toolkit which is structured so that it can be used in fields which can benefit from spatial analysis but which are not traditionally involved in GIS. The materials, which are of a laboratory or practical type, are based on accepted GIS concepts and techniques, and are highly interactive, consisting of data sets, case studies and flowcharts which can be accessed via the SPANS GIS software, are adaptable and can be customized to suit the user. This type of 'user-friendly' GIS curriculum material will greatly expand the use of GIS in education.

Introduction

The original purpose behind developing GIS was to store and access maps in digital form, especially those related to rural land use and natural resources (Tomlinson, 1984). Subsequently, GIS developed more analytical purposes as it was realized that digitally-stored georeferenced data are ideal for spatial analysis and that spatial analysis could improve the understanding of map information. The develop ment of GIS and the difficulties associated with the cost and limited power of computing technology during the 1960s created a pioneer spirit among the early GIS developers who were usually geographers, often those specializing in cartography. GIS pioneers typically possessed strong academic backgrounds in geography, cartography, surveying or applied mathematics, and werecomfortable with computing and programming.

In recent years GIS, has been adopted by many businesses, industries and academics and operated by personnel who are weak in one or more of those areas of traditional strength. This has worked in favour of those commercial GIS programs which have a 'user-friendly' interface and are menu-driven rather than command-driven. It has also caused some criticism of the new 'softball' GIS users (Douglas, 1988) and some fear that GIS techniques may be misused due to ignorance on the part of the user of some basic concept or technique in geography, mathematics, statistics or computing. Similarly, GIS pioneers worry about proprietry software code, fearing that the 'black box' implied may mishandle data in spatial statistical operations.

At the same time, many GIS pioneers accept that GIS is a tool of enormous potential which can be used for the good of humankind in a very large variety of applications. Focussing on this, it seems appropriate to solve the problem of potential misuse of GIS by operators with a background deficiency. The Canadian Centre for GIS in Education believes that this end is best served by developing interactive, computer-based learning exercises which can be used to help GIS operators, whether technicians, managers or academics, to apply GIS techniques appropriately, and to appreciate the range of applications and techniques which may be brought together. The Curriculum Development Toolkit has been created by the Centre to achieve this end.

The Canadian Centre for GIS in Education

The Canadian Centre (CCGISE) has been described as representing a new partnership between academics and the GIS industry (Rogerson, 1990). Although it was formed by TYDAC Technologies of Ottawa, the company which developed and sells SPANS GIS software, the management of the Centre, and much of the material produced by the Centre is in the hands of academics. As a result, prices of SPANS software have been radically reduced for academic users, and the Centre has made a commitment, supported by TYDAC, to serve the academic community through an awards program and through acting as a 'clearing house' in the distribution of GIS case studies and exercises based on SPANS.

The Curriculum Development Toolkit

A prototype of a toolkit was developed by TYDAC in early 1990. It was distributed to academic SPANS users in North America, Europe, Australia and Asia. The feedback obtained from this process resulted in a substantially changed document. This document was tested at two workshops, the first in August 1990 at Queen's University, Kingston, Ontario, and the second in Manchester, UK in November 1990. These workshops gave a good indication of the performance of the interactive learning units, and allowed the Centre to incorporate some improvements to the material, even at a very late date. The first stage of the Toolkit has now been commercially released. It consists of the core interactive Learning Units, with supporting material that is both generic in GIS concepts and techniques, as in the Background Units, and system- specific, showing one how to perform various analytical tasks on SPANS, as in the Orientation Units. Purchasers not only get the first stage but they will also receive up to a further 25 Learning Units, and many more case studies, during the next six months.

No specific audience is addressed in the material, neither in terms of educational background or attainment, nor in terms of disciplinary interest. 'Welcome to GIS', the initial chapter in the Toolkit could be read with profit by high or junior high school students. The first Background Unit provides a deeper treatment of the same kind of introduction to the development of GIS and the kinds of applications and concerns which are current in GIS.

CURRICULUM DEVELOPMENT TOOLKIT
Stage one: October 1990

Welcome to GIS

Background Units
A - Introduction to GIS
B - Geographic Data as a Model of Reality
C - Visualization of Spatial Data
D - Transformation of Spatial Data

Orientation Units
1. Examining Geographic Data using SPANS
2. Creating a Cartographic Image
3. Spatial Query
4. Creating a SPANS study area

Learning Units
1 - Map generalization
2 - Logical overlays - Impose overlay
3 - Logical overlays - Map mosaic
4 - Logical overlays - Combining map layers
5 - Spatial measurements - Area analysis
6 - Logical overlays - Matrix overlay
7 - Arithmetic overlays - Index overlay
8 - Proximity analysis - Buffers and corridors

Case Studies
  Soil Type generalization
  Urban unemployment impose overlay
  Urban land use map mosaic
  Forest fire history combining map layers
  Urban area analysis
  Crop yield estimates matrix
  Water acidification sources matrix
  Tree harvesting suitability index
  Hazardous waste siting proximity

Instructional Tools
  Customizing the Toolkit exercises

Table 1: The Structure and contents of the October release of the Curriculum Development Toolkit

The Learning Units are structured such that they begin by describing a technique or concept used in GIS. For instance, Voronoi diagrams or Thiessen polygons are described in terms of the way they are constructed and the properties of the polygons relative to the points from which they were formed. Three typical applications of the Voronoi diagram technique are then discussed, and the student is led through a slide display to illustrate both the process involved and the Voronoi diagrams created in the three case studies, using real data. After the slide show, a dataset is introduced and the student is led through the process of creating a Voronoi diagram in a generic sense. After this, the procedure for creating the diagram using SPANS is outlined. In most Learning Units, the SPANS procedure follows the same logical steps as the generic process.

The Learning Units are completely interactive. Those dealing with index overlay and matrix overlay techniques allow students to introduce their own qualitative weighting of variables. This helps students to understand how data can be manipulated and why it is important to bear all stages of analysis in mind, from objectives to techniques and data quality when using the results of a GIS analysis.

The flexibility of the materials is underlined in the fact that the computer-based exercises are customizable. If a particular example is unsuitable, a professor or teacher can remove the example and replace it with one based on her or his own data set. Blank templates are provided for customizing the 'story-boards' and flowcharts used in the slide show for each unit to facilitate this process.

One of the most exciting parts of the Toolkit is the Case Studies section. Case studies are taken from a diverse range of academic areas, from marketing to agriculture, forestry, entomology, hydrology and pollution control. Many academic SPANS users have agreed to provide new case studies, some with complete data sets, for distribution by CCGISE to other academics. These will provide a rich source of material for laboratory teaching purposes.

The Future

When the Curriculum Development Toolkit is complete in terms of the number of Learning Units, CCGISE will focus on constant updating and modification as better material, examples or techniques evolve.

Co-operative projects in GIS will become a larger part of the Centre's activities. At present, CCGISE is involved with Queen's University and a School Board in eastern Ontario, in a project to develop materials for using GIS in teaching elements of the high school geography program in Ontario. The project is currently supported by the Ontario Ministry of Education.

This and other similar projects will see GIS migrate even further from its traditional core of users in the educational sector. This will put considerable pressure on CCGISE to develop materials which are user-friendly and 'foolproof'. Much of this pressure will be passed on to the GIS industry, specifically TYDAC, in the case of CCGISE, and should result in better software and interfaces which accord with user demands. It is clear that student versions of GIS software must be developed to complement the fully functional professional software on which the curriculum materials are developed. It will be important to ensure that these are fully integrated in to the learning program.

CCGISE will experiment in customizing a Toolkit for a single academic area, such as geology or marketing. All the examples used in that version of the Toolkit will relate to the theme discipline. It is unlikely that this will become a major preoccupation of the Centre, but will serve to illustrate that such broad-scale customization is possible, and that we must expect that GIS is taught in programs other than geography and survey engineering.

Conclusion

The Canadian Centre for GIS in Education can assist a wide range of teachers, professors and instructors in developing computer- interactive teaching of GIS concepts and applications, or in introducing GIS into a diverse range of disciplines as an appropriate technique to improve the understanding of their discipline. The future of GIS in academia is likely to be concerned as much with the spread of GIS into a wide range of disciplines, academic levels and courses, as it is with the development of new and better analytical tools. Canada can lead in this, as it has in many GIS developments in the past.

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GIS Implementation and Training Issues

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Abstract

There are many factors to be considered with respect to successful GIS implementation. These include user need studies, GIS hardware and software selection, data capture, application development and training. For most organizations, a tremendous amount of time and energy is spent assessing the available technology: hardware, software, communications, application development and cost. As GIS technology advances, options for hardware and software increase.

Just as important as selecting the GIS hardware and software to meet user needs is planning for the implementation of the GIS within the organization. This involves outlining short and long term projects that will involve GIS and the staffing of these projects. Staff reorganization and training to accommodate this new technology is absolutely critical for the successful implementation of the GIS.

In this paper, issues of staffing GIS projects will be discussed. Options for training programs will be outlined and alternatives to staffing and training within existing organizations will be presented.

Concurrent Session 16

Corporate GIS

A Corporate GIS Prototype

Creating a Corporate Graphic Data Base: a Manager's Perspective

Ten Steps to a Successful GIS

GIS'91

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A Corporate Geographic Information System Prototype

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Abstract

The Surveys and Resource Mapping Branch recently developed a functional prototype of a corporate GIS for the Ministry of Environment. This work is being carried out under a protocol agreement between the ministries. The focus of this exercise was on integrating geoprocessing capabilities at the core business level of an organization, supporting a wide variety of business applications. A number of technical issues associated with accessing, updating, and managing corporate land information in a multi-vendor distributed environment were addressed. Coordinate data in non-relational format and business data in various relational data structures were both supported. The design also respects the B.C. Corporate Land Information Strategic Plan (CLISP) philosophy of shared data and considers the conceptual role of the BC-SAIF interchange format.

Introduction

The British Columbia Ministry of Environment has initiated a corporate geographic information system project which will enhance its ability, through the Ministry programs, to carry out its mandate of managing the environment. This project has been under the technical leadership of the Surveys and Resource Mapping Branch, which is situated within the British Columbia Ministry of Crown Lands. This intergovernmental project is formalized by a protocol agreement which establishes the responsibilities of the two Ministries.

Due to the complexities of the work involved in developing and implementing a corporate geographic information system and the desire to minimize the disruption to ongoing activity in the Ministry of Environment, the project is structured into three phases: Prototype, Pilot and Release. The Prototype phase addresses the technical issues required for accessing and sharing information between programs of the Ministry of Environment which would use the geographic information system. The Pilot phase will address the performance requirements of the system in an operational environment. The Release phase deals with implementation issues of the Ministry of Environment, province-wide corporate geographic information system design. The project is currently in the Prototype phase.

Background

The Surveys and Resource Mapping Branch is promoting the introduction of GIS technology at the core business level of the organization. This concept extends to all levels of the organization and supports a wide variety of business applications from administrative queries to complex modelling. This approach to corporate GIS means that all GIS uses are considered within a single context and that the relationships between the different organizational components of the Ministry are understood and optimized.

The Surveys and Resource Mapping Branch's report, entitled **General Requirements and Preliminary System Design**, 1989, developed an overall concept for such a system and presented an example of a preliminary system design. The Branch's preliminary design identified the need for local area networks and servers, distributed data management, common standards and specifications, and respected the Ministry of Environment technology architecture. A number of technical issues associated with accessing, updating and managing Ministry of Environment corporate land information in a multi-vendor, distributed environment were not resolved by the preliminary design.

A subsequent project was undertaken to extend and refine the preliminary design to address many of these unresolved issues. This project was the initial system design. A detailed system design based on the recommendations of this project, detailed user requirements, data resource management plans, and Ministry communications architecture will follow.

The initial system design project consisted of a conceptual design (paper system) as well as a physical demonstration of the design (prototype system). The project requirements included providing access to multiple DBMS, integrating multiple GIS products, providing a means of managing associated business data in a distributed regional environment, providing off-line execution as well as interactive GIS, and providing a simple user interface to the GIS.

Conceptual Design

With the emphasis of the Ministry of Environment GIS initiative on regional operations, the design infrastructure and subsequent prototype reflect regional requirements. The design was partitioned into a regional GIS infrastructure and a regional business infrastructure. Functional analysis of each component produced a model of information flows which was then translated into a technical design. Each of the features of the conceptual design can be mapped back to the original project objectives.

The characteristic features of the initial system design are briefly described below.

Client-server architecture

The principal of 'divide and conquer' gave rise to the client-server architecture, in which specialized processors are dedicated to specific functions, in service to client processors which execute applications for the end-user. This architecture is particularly applicable to distributing geoprocessing, given the enormous volumes of data associated with GIS and the computer resources required to support the complex spatial queries. Although the demonstration prototype described later employs only one server, the design supports the notion of multiple special function servers (GIS servers, database servers, file servers, disk servers, a master server running other servers, et cetera).

Connectivity

Backbone network connectivity, which connects each processor with all other processors, is applicable to the local area network of the regional infrastructure. This architecture will ultimately be extended to include WANs, potentially extended LANs, relays, bridges, gateways or routers, et cetera, to interconnect all Provincial Ministry of Environment programs. Design and implementation of this communications architecture is currently being undertaken by the Ministry of Environment in conjunction with the British Columbia Systems Corporation.

Server-based GIS

For the community of users who normally use the standard, or server-based, GIS software available to a broad range of users, generally non-specialist users or non-graphic business applications. Server-based GIS refers to the fact that a 'server', normally a multi-user processor is executing the GIS software. The design does not preclude the use of multiple GIS servers offering a variety of vendor products for server-based applications.

Client-based GIS

Client-based GIS provides unique analytical capabilities to GIS specialists. In this instance, 'client-based' refers to the fact that a client, normally a single-user processor, is executing the GIS software.

Distributed data

Each region would maintain a repository of geographic data, both baseline and business. The regional repositories would consist of a partition of the provincial master geographic database. Associated business or administrative data will be distributed between headquarters and the regions.

The business data infrastructure deals with the management of non-spatial data with a view towards the sharing of business data among applications, both GIS and business. Two solutions were offered for satisfying the business data infrastructure. A business data gateway which determines the location of requested business data through a 'meta-database', and returns appropriate tables to the requesting GIS. The other approach provides access to data using a business data repository which has been aggregated, in a standardized format, from the various regional line agencies as well as with centrally managed data from headquarters. With both approaches, the underlying assumption is that business databases should not be required to be implemented with an identical DBMS product. The repository approach was ultimately implemented for the demonstration prototype. It offered fewer management problems and the degree of technical sophistication and risk would likely be less than with the gateway approach.

Translation services

Planned data redundancy was designed to alleviate performance constraints associated with on-line conversion of BC-SAIF formatted data. BC-SAIF represents a comprehensive set of specifications appropriate for spatial data management and data sharing. Translation servers will provide the two-way translation between the non-proprietary format (BC-SAIF), and the proprietary formats required by the server-based and client-based GIS.

Physical Prototype

Over the years, many system designs which have appeared infallible at the conceptual and logical design stages, have totally broken down upon implementation. The demonstration of the physical prototype was required to ensure design integrity. As it was neither appropriate nor realistic to prototype all aspects of the design, the following objectives were identified for the functional prototype:

1. Illustrate the role that BC-SAIF could play in a regional GIS infrastructure;
2. Demonstrate the function of an Application Program Interface (API) which will allow a non-graphic business application to initiate a server-based GIS procedure which returns a tabular result;
3. Demonstrate a GIS-based application which has the ability to access and update business data residing in various formats and locations;
4. Demonstrate the function of a Business Data Repository management system; and
5. Demonstrate a GIS user interface which provides simple operation.

The prototype development was considered exploratory in nature. While it was intended to overcome some of the key technical difficulties, it was not intended to be implemented as a pilot or a production system.

The implementation of the prototype was influenced and constrained by the capabilities and current technology architecture of the Ministry of Environment. The prototype was assembled with the following components: a MicroVax 3100 (VMS) as the host for the server-based GIS, PC 80386SX (DOS), Macintosh IIcx (Mac OS) used in terminal emulation mode, an Intergraph InterPro 3050 (UNIX) and non-graphic, diskless VT terminals; connectivity was provided by thinwire Ethernet and DECnet Local Area Network Protocol.

Simulated business applications which exploit the functionality of GIS and represent typical operations of the line agencies in Ministry of Environment were developed to demonstrate how each of the prototype objectives were addressed. These included a Water License Clearance System, a Waste Loading Analysis System, a Wildlife Management System and a Pesticide Control Application.

The applications attempted to capitalize on existing Ministry of Environment and Ministry of Crown Lands data. TRIM program 1:20 000 data and 1:250 000 data which the Surveys and Resource Mapping Branch is currently enhancing and re-structuring, was used as the standard baseline framework. Additional business-geographic (thematic) data was then referenced to these baseline products.

The required thematic layers were, in many cases, already available in a variety of digital formats, including IGDS, PAMAP, PC Data, and ARC/Info. Conversion routines such as SIF, DXF and other custom written routines, were used to transform the various input formats to the proprietary formats of the server-based (host) GIS and client-based GIS, in this case, Arc/Info and IGDS. Typical conversion problems were encountered, such as different working unit or units of resolution, differences in the definition of global origins or design planes, incompatible conversion of symbols, cells, fonts, and conflicts between export and import formats related to attribute field definitions.

The associated business data was somewhat less complicated. The prototype design, which details a regionally centralized business data repository, utilized DEC's RdB product on the MicroVAX host. Business data was transformed from a variety of relational formats into RdB tables. Existing tables were enhanced by a single field (spatial key) which was required to ensure compatibility between the graphic and non-graphic data. The prototype also demonstrated how business data generated in dBASE III+ could be aggregated into the RdB repository.

Prototype Findings

The role of BC-SAIF

Although the efforts of BC-SAIF and this prototype GIS were not synergistic, one objective of this project was to discuss the conceptual role of BC-SAIF in a regional GIS infrastructure.

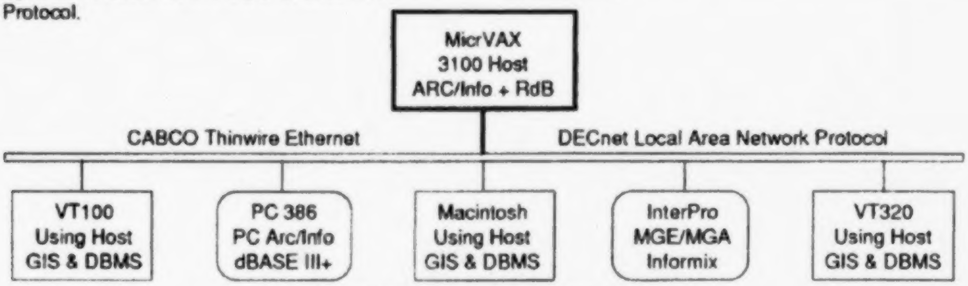

Figure 1: Physical topology of the prototype.

In order to describe the relationship between geographic information systems and BC-SAIF, the specification of BC-SAIF introduces the Geomatics Information Architecture (GIA). The GIA attempts to decompose GIS into three distinct layers; the geographic information system, the database management system, and the communications network. This allows development to proceed within each layer, but independent of the other layers. Cartographic concerns are independent of data management concerns which are independent of computer networking concerns. BC-SAIF falls primarily in the middle layer of the GIA, the database management system, which is founded on the ANSI Three-Schema Architecture.

The data translator identified in the conceptual design mandates the existence of an appropriate interchange format such as BC-SAIF. Recognition that the adoption of common models for expressing and transferring information to facilitate communication between provincial agencies was paramount in the preparation of the initial system design.

BC-SAIF has a significant role to play in the initial system design through facilitating the development of standards, and the use of spatial data in diverse applications and environments. Should it be accepted by the user community, BC-SAIF will have a major positive impact on the implementation and effectiveness of GIS technology.

The function of a GIS application program interface (API)

Two of the simulated business applications developed for this prototype demonstrate how a non-graphic business application could pass a request for geoprocessing services to the host (server-based) GIS and receive tables of data that have been spatially processed.

These requests, which can be made quite independently from the graphics environment, may be entirely transparent to the user. This is a very powerful concept when considering enhancing existing business applications or developing new applications which benefit from the dynamics of geoprocessing. These requests can be executed by a character-based business form and a user with no knowledge about the operation of GIS software. Applications which lend themselves to this type of execution include simple and complex queries which do not involve modification of spatial objects, do not require a graphic display, and are repetitive in nature.

Although the execution of the GIS application is transparent to the end-user, the prototype applications are not transparent to the data or the network services and resources. There is no single homogeneous API. To write the applications, the developer must have prior knowledge of database location, data structures and definitions, and knowledge of many data manipulation languages and network protocols.

There is a great deal of work being done in this area to assist systems engineers in developing systems in a distributed heterogeneous environment. The center of this thrust towards open systems is the International Standards Organization (ISO). The ISO have endorsed the Open Systems Interconnection (OSI) Reference model (IS7498) as the guiding principle for the design and analysis of computer networks. The OSI model is a seven-layered model, each layer performing a different function in the network. Like the ANSI three-schema architecture mentioned above, the OSI model allows partitioning of the network architecture into functional layers, effectively reducing the design and analysis of the overall network into more manageable design problems. At each node in the network, layers communicate with other parallel layers by means of predefined protocols. Software on two different nodes can effectively exchange information using the established protocols between the various layers, without any knowledge of the physical transfer mechanism. The effective result is that software responsibilities can be specialized and systems from a variety of suppliers can communicate harmoniously. Implementations of OSI protocols are emerging and product offerings are becoming available. By the mid 1990s, industry standards will be in place which will provide practical architectures and methodologies for open system development.

GIS applications accessing and updating multiple business databases

This objective was met without reservation. Demonstration applications created, maintained and manipulated local databases of spatial and associated attribute data as well as accessing attribute data in the business data repository. ESRI's development of a relational database interface (RDBI) for the RdB product was concurrent with this project and provided an access path into the business data repository.

GIS vendors have begun to integrate their proprietary geographic information systems with commercially-available database management Systems. Some of these integration efforts have taken advantage of OSI standards like Structured Query Language (ISO 9075), which facilitates the management and transfer of business data between the GIS and an SQL-compliant DBMS. This was the case with the prototype applications communicating with RdB and Informix relational DBMS.

The function of a business data repository

Although not the 'ideal' architecture, the prototype repository provided a functional solution to the creation and maintenance of a sharable database of business information. The host procedure aggregates the contents of server-based and client-based business applications, which are distributed in various formats, into a sharable read-only database in a standardized format on the host.

Data management, particularly in a distributed environment, raises issues such as integrity, security, backup, et cetera, which are not resolved by current GIS technology. These data management concerns are largely an organizational problem which must be addressed by a complete business solution. The coordination of graphic data with non-graphic business data in a corporate infrastructure creates additional data integrity concerns. The two data types have traditionally been managed somewhat independently of each other, which will inevitably lead to synchronization anomalies. When additions and/or deletions occur in one domain (graphic) and not in the other domain (non-graphic business data) concurrently, these compatibility concerns become apparent and are referred to as 'spatial referential integrity' problems. The integration of GIS must be a part of the business plan and is no longer merely a technological solution.

Again, the initial system design offered a gateway approach as well as the repository approach. Although the repository was prototyped, the ultimate solution would likely be a hybrid approach incorporating aspects of both the gateway and repository methods in a unified architecture.

A simple GIS user interface

When introducing geoprocessing capabilities to all levels of an organization, consideration must be given to the eventual users of these systems and the way in which they interact with them. The user interface component of these systems must be able to be customized to the specific job functions, needs and abilities of these users to allow for a clear concise dialogue to take place, while at the same time, hiding much of the overall complexity of the system. Both of the GIS products used in the prototype, ESRI's ARC/Info and Intergraph's MGE, have enough maturity and flexibility in their Graphical User Interfaces (GUIs) to address the needs of expert users and beginners alike. They both contain a rich set of commands and functions for interacting with the system or for customizing the system to meet the specific requirements of the organization.

The application developer should have complete control over the appearance of the menus for each application. This means that, at any given time, only the relevant commands for performing particular functions are visible to the user on menus and available to invoke commands. Customized menus might include application-specific menus, or be used to limit or extend the range of GIS functionality based on user expertise or application requirements. The GUI makes extensive use of a pointing device (mouse), thus minimizing the amount of operator keystrokes. A sophisticated procedural command language is also required to allow the application developer to group system commands into macros or programs for execution. As noted above , in the discussion of the application program interface, this facilitates the use of the system by the largest population of corporate users: the casual user.

Conclusions

The implementation of a corporate geographic information system for the Ministry of Environment is technically feasible. The initial system design and subsequent prototype demonstrated the ability to effectively customize the execution of the GIS software, to implement distributed technology, and to adhere to the evolving guidelines for data sharing as set forth by the Land Information Strategic Committee (LISC). LISC is an intra-ministerial executive committee coordinating a government-wide land information management strategy.

A number of data management issues raised, but not resolved in this prototype, include database contention, two-phase commit, query decomposition and optimization, data encryption, and maintenance of the integrity between graphic and non-graphic business data. Data security and integrity issues must not be minimized.

Multiple hardware platforms can be accommodated, from low-end non-graphic terminals to mid-range PCs and workstations as well as high-end servers performing specialized functions. A variety of GIS products were integrated and supported by this design, with centralized GIS services for a broad range of users, as well as a number of specific products and systems necessary for those users with specialized requirements. Effective data sharing can be realized in a number of ways. Repositories of shareable information can be aggregated from multiple distributed DBMS in various formats, gateways can be used to directly access distributed data in various formats and BC-SAIF and proprietary formats can co-exist.

Although the prototype implemented primitively specified design protocols, the underlying principles which facilitate data integration in a multi-vendor, distributed environment are a common data model, such as BC-SAIF, the recognition by software engineers that designing software using the OSI model will facilitate interchange between system parts, and that the ISO standard SQL be adopted for manipulation of associated business data. The future direction of corporate geographic information systems will be based on designs which are specified in terms of a coherent, layered framework which embrace recognized standards.

In this atmosphere of ever changing technology, adherence to recognized standards such as the OSI model, will ensure compatibility with a large number of organizations including the ability to link together systems which were not originally intended to be linked. This will provide a 'future-proof' design which can accommodate new technology. As changes related to open systems and inter-operability are just beginning to occur, decisions organizations make today may affect their future ability to exploit that potential.

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Creating a Corporate Graphic Database: A Manager's Perspective

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Abstract

Various provincial agencies in British Columbia have been producing digital maps for a number of years. The process each agency uses duplicates much digital data, but a recent case study has brought these agencies together. The case study standardizes depiction, captures data using specific rules and moves information between agencies in a standard archival and interchange format. This paper, from a non-technical manager's perspective, discusses some of the problems and successes associated with multiple agencies contributing to a corporate graphic database. A basic review of the pilot project is presented.

Background

In British Columbia, two ministries, Crown Lands and Forests, are major electronic mappers. Crown Lands is responsible for topography, planimetry, cadastre and Land Act tenures. The Ministry of Forests has the mandate to graphically represent forestry themes. This translates into forest inventory, forest tenures and forest related administration boundaries.

Within the Ministry of Crown Lands, the Surveys and Resource Branch is responsible for producing planimetry and topography. The Surveyor General's Branch, part of the same Ministry, maps all primary survey parcels, leases, legal rights of way, authorities to occupy, associated administration boundaries and other similar areas of interest. The Timber Harvesting Branch of the Ministry of Forests captures all forest and range tenures, restrictions related to forest activities, and administration boundaries related to forest and range activities. The Inventory Branch of the Ministry of Forests maps timber types and forage classifications.

In the recent past there has been little data sharing. When available, the Inventory Branch would use pre-North American Datum (NAD) 1927 information from Crown Lands. When not available, they would create their own databases. The Timber Harvesting Branch is a more recent entry into the electronic mapping environment and has used Ministry of Crown Lands databases for all their work, which is based on NAD 1927.

All the graphic data captured to date, in a production environment by all four of these players, has been topologically unstructured, captured using inconsistent capture rules to generally inconsistent standards and to non-compatible specifications using vendor-dependent formats. There is one major exception which will be discussed shortly.

This lack of coordination between ministries and branches, notably the Timber Harvesting and the Inventory Branches has resulted from:

1. electronic mapping activities starting at different times;
2. traditions associated with manual mapping being extended into the electronic environment;

3. different end products requiring decidedly different levels of accuracy; and

4. the normal biases and feelings of ownership associated with agencies competing in the same arena.

Terrain Resource Information Management (TRIM)

TRIM is the one exception mentioned above. It is a recent B.C. mapping project that provides digital baseline topographic and planimetry information at a 1:20 000 scale in a non-proprietary format. Data is captured to rigorous specifications. All data passes through a series of quality assurance steps. The Surveys and Resource Mapping Branch oversees this project, which began in 1986. Approximately 1 500 of the 7 000 files (mapsheets) required to cover the Province at 1:20 000 scale are complete. The initial learning curve was steep but the production rate now stands at about 600 files per year.

This graphic data is cartographically clean: all polygons close; all intersections are noded; and rules defining adjacency and connectivity are followed. All water courses are captured according to the downstream rule and polygons are defined by the right-hand rule. This data, in comparison to the NAD 1927 data previously being captured, is consistent in quality and precision.

The non-vendor dependent data exchange format being used for this project is called MOEP, after the Ministry of Environment and Parks, which at the time was the Ministry responsible for TRIM. This format is limiting in that it can specify graphic information only and has no ability to represent attribute data. Translators exist that convert MOEP files to most vendor formats used for data capture, display, analysis, updating and amendment purposes.

The Concept of a Corporate Database

Everyone agrees that graphic data presently being captured by both Ministries is a corporate resource; agencies other than those capturing their specific information have a use for it. This includes users outside as well as inside the government. And it makes good sense that information should be captured only once. If the Ministry of Forests needs legal survey information, it should be supplied by the graphic information experts in that mapping field, which, in this example, is the Surveyor General's Branch. The Ministry of Environment should be able analyze the affected downstream hydrology of a chemical spill without having to build connectivity and downstream rules into data they receive from the Surveys and Resource Mapping Branch.

In order for information to be compatible across mapping disciplines there are a few basic concepts that everyone can support in theory but often find it difficult to agree to in practice:

1. standard specifications;
2. standard capture rules; and
3. standard transfer format.

Standard Specifications

Standard specifications basically say that all 'mappable things' that are alike will be graphically described the same way. As an example, a river is different from a stream and will be depicted differently, but all streams will be depicted the same way, using the same codes and all rivers will be depicted the same way, using their own codes. The only difference between streams will be location, the only similarity between rivers will be depiction. The key point is that a unique identity is tied to each feature.

The second component is the precision and accuracy at which data is captured. Precision refers to the number of decimal places that will be stored for a particular feature. In a practical sense, precision is only applicable to data captured by coordinate geometry (COGO). Accuracy, in the context used here, refers to how precisely an operator can actually represent a feature on a map, by digitizing, with respect to how it really exists on the ground. At best, this becomes an educated guess.

Standard Capture Rules

Simply stated, by following some basic data capture rules, you can embed some Neanderthal intelligence into your data that can be built upon in the future. For example:

1. by digitizing water courses 'downstream', you can preserve the ability to ask questions of your data that rely upon water flowing downhill;

2. by associating a point, line or polygon with a particular feature, you can construct the topology of the feature; and

3. by capturing polygon boundaries such that the inside of the polygon is always defined as lying to the right of the boundary, polygons within polygons can be identified.

Without applying consistently data capture rules, you cannot associate or predict meaningful relationships between data.

Standard Transfer Format

A standard interchange format is a critical factor in graphic database scenarios where various players are capturing data within their areas of expertise, but sharing the outputs with others. I liken it to a series of different spoken languages. I may be able to express myself best in Polish, you in German, another person in Italian and a fourth person in French. Common to us all is a universal language such as Esperanto. This universal language is not nation-, or in the case of data, vendor-dependent. We should do our work in the format that best suits our needs and traditions, yet exchange our work in a non-vendor dependent format.

By exchanging data in a non-vendor dependent format, all data contributors must meet minimum specifications. The data receiver knows the data will be consistent in quality, precision and accuracy. Thus, it has the added advantage of keeping all players honest with respect to data quality.

The Queen Charlotte Islands Case Study

In May of 1990, a number of ministries in B.C. established a small working group to conduct a corporate graphic database pilot project. Once again, the major players were from The ministries of Crown Lands and Forests, though the ministries of Transportation and Highways, Environment, Municipal Affairs, Parks, and Agriculture and Fisheries did participate as well. The Corporate Land Information Strategic Plan (CLISP) is presently being developed for B.C.; its expectation is to provide a blueprint for exchanging land related information. The Queen Charlotte project was a practical hands on project, driven by the working level of the participating ministries and was intended to supplement the CLISP initiative at the working level.

The terms of reference were modest. Its purpose was to establish a suitable environment for the capture and transfer of a variety of resource based data, which can be geo-referenced, primarily between the Ministry of Crown Lands and the Ministry of Forests, in conjunction with other committed ministries.

Administrative and technical aspects of sharing data between participants were identified and addressed by:

1. defining data capture specification and extending the MOEP specifications to include the data from all participants;
2. capturing data using TRIM-like data capture rules; and
3. performing quality assurance checks on the data to a TRIM-like level.

From the very beginning, the intention was that this case study would be a learning exercise. The specific goal of the Timber Harvesting Branch, however, was to use what was learned as the basis for their mapping in areas where NAD 1983 data was available.

The specific deliverables identified in the terms of reference were:

- data specifications for each participant's data;
- quality assurance procedures;
- data capture procedures;
- actually capturing graphic data using the previous specifications and procedures over a selected area; and
- a report documenting these activities and recommending further action.

Three mapsheets on the east shore of Graham Island, in the Queen Charlotte Islands, were chosen. Choosing three mapsheets was viewed as a modest undertaking that each participant could manage, yet at the same time, would provide ample scope to experience most problems. Additionally, it provided the opportunity to address edge-matching concerns since the mapsheets were adjacent. Other specific reasons for choosing these three map sheets were:

1. TRIM files were already available for this area;
2. The Surveyor General's, Timber Harvesting and Inventory Branches all have a moderate amount of activity in the area; and
3. other non-mapping ministries have selected information available which could be graphically represented.

The Surveys and Resource Mapping Branch already had their end product in the form of TRIM files for the case study area. The Surveyor General's Branch, Timber Harvesting Branch, and Inventory Branch had to produce specifications, load data to those specifications, perform quality assurance checks and then put it into MOEP format.

The three remaining branches began setting specifications by first listing all the features that would be captured. This was a simple process, since most features were already being captured in their ongoing mapping initiatives. Then responsibility for capture was negotiated between the players. This was more difficult, since many features are already being mapped by more than one of the three. This was followed by setting a capture standards such as accuracy and precision. With this accomplished, each branch proceeded to write their data specifications.

With draft specifications in hand, data loading began. Procedurally, timber tenure information could not be loaded until cadastre was available: the point of commencement for timber tenures are legally described from known survey points. These types of data relationships exist between all of the players, though at varying degrees. In the past, data was shared when and where available; where it was not available, each mapper would capture any information they deemed necessary to do their tasks.

The Surveyor General's Branch completed their information and ran it through quality control. The Timber Harvesting Branch then referenced both the TRIM and Surveyor General's Branch files and captured timber and range tenure information. This, too, was quality assured. The Inventory Branch then mapped all timber types to complete the cycle. Each time a file was completed, it was translated into MOEP format and passed along, with all previous files, to the next mapper.

The end product was four separate positional files, all with non-redundant data captured to predetermined specifications at the same positional accuracy and precision.

Further, the data resided in a non-vendor dependent format. Since all data was captured according to specified rules that maintained data structure, it was then possible to build a topology for each feature. This meant that polygons could be geo-referenced. Not just polygons on each file, but polygons could be mixed and matched between files. As an aside, some attribute data was attached to some of the polygons to make the GIS queries more realistic.

Conclusion

What was learned from this exercise?

First, the foundation for a corporate database is transferring information between users. This implies that numerous players will be capturing information, as well as using other players' information. This case study showed that moving information around in a standard format worked well. Because the format was non-vendor dependent, any system could work with the data, provided that a translator was available and a number of translators do exist.

Second, by adhering to specified data rules, information captured by one participant could be used in the same analytical way as data captured by any other participant. This includes being able to copy, on to your file, lines from a feature that resides on another player's file. Both lines are coincidental and remain positionally correct. For our uses, the rules associated with topological integrity are extremely important. But looking into the future, rules such as connectivity, downstream and others are also very important.

Third, quality assurance is paramount. Data is being captured using various systems and different formats. We found that the standard quality control software supplied by vendors was not always adequate nor was the custom quality assurance software written for the TRIM program. In all likelihood, custom quality assurance software will be required for each contributor to the corporate database, unless there is standardization on data capture software. Even then, there may be sufficient data differences to complicate the quality assurance tasks.

Fourth, the users of the data are faced with graphically representing the positional file in hard copy since no representational files were built. Some features are made up of lines and points that are coincidental with each other, that is, they lie on top of each other. In these instances, one boundary of one feature is very difficult to distinguish from other boundaries. As an example, there are instances in the Timber Harvesting Branch where lines are stacked seven deep. To date, there are two methods to deal with this problem:

1. at the time of data capture, build a representational file with all the coincidental lines offset. The additional staff time, disc space, file management and overhead problems are obvious; or
2. use colour fill. This is not always desirable because colour fill has it own overhead problems associated with creating the colour fill both on screen and on hard copy.

We are presently experimenting with electronically offsetting lines. To date, we are encouraged with our success.

To conclude, the Queen Charlotte Islands case study has encouraged all the participants to continue down the corporate graphic database path. The formal process will continue through the CLISP initiative. At the same time, valuable information has been gained which will assist in future decision making and will give direction to the Timber Harvesting Branch's mapping initiative.

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Ten Steps to a Successful GIS

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Abstract

A geographical informaiton system is the embodiment of large-scale organizational practises. Paradoxically, many organizations undertake a GIS implementation without adequate preparation, exposing themselves to unnecessary stresses in both budgets and personnel. Major failures may result. Ten general but battle-proven steps to facilitate the process are presented.

Introduction

A GIS system may be the most complex project ever undertaken by an organization. There are many steps that an organization must take to develop a successful GIS system. Much has been written about these issues over the last several years. There are suggested methods of defining the data layers, determining color and shading methods, selecting a consultant, etc. As an industry, we have no loss for advice on organizing our GIS. The problem that many face is one where the organization must change in order for the project to be successful.

We all know what hardware and software are, but a new term has emerged recently, 'Orgware'. You may want to define Orgware as the instructions available to any organization on how to properly succeed in its task.

There are many steps to be taken toward successful completion of a project. These steps have been used over and over again and are believed to be universal principles. They are not ideas that are made up for a particular project or a particular event. In this paper, these steps have been digested down into 'Ten Steps For A Successful Project'. They can be used not just for project management but also for managing your personal life. In this paper the emphasis and examples will be for producing a successful GIS project.

Step 1: Review Past Projects

When you're starting off on a major project, one of the first things you have to do is review all the things you've done before: review your past projects, take a look at what you've done before. Make a list of them. Sometimes, organizations really don't understand what they've been doing. Often there is turnover within organizations and some of the newer people don't realize that they are part of a major effort which began in years previous and that they are now seeing the benefits of that effort. What did you learn from these projects? What did you gain from them? When you make a mistake, seize the opportunity to learn from that mistake.

Many people know the frustration of starting on a project and when a problem developed, they stopped that project and then started another one and the next project they did exactly the same way. If you do things the same way, you're going to get the same results over and over again. Try something different. Learn from the mistakes and apply the improvements on this new attempt.

Many organizations perform what's called a project post-mortem. When a project fails or when a bid is lost, you do a post-mortem on it: What did we do right? What did we do wrong? How would we do this differently if given the opportunity?

GIS is probably one of the most complex projects you'll ever be involved in. It is significantly more complicated than adding a few PCs in the office for word processing. Because of the power of GIS and the many diverse groups that could be involved in its implementation, you have the opportunity of changing the way your entire organization does business. This is very hard to do if you are sitting with an entire office full of other things that you are trying to get accomplished. You cannot do what you are doing now *and* develop a GIS at the same time. Many professionals have file drawers of old projects. Some of these old projects just need to be completed by writing the final report. Devote the time to clean these out.

Determine what you can't do and make a decision not to do it. There are things that probably can't be or shouldn't be done. Get rid of them. You must free yourself of your old projects; complete them or get rid of them!

Step 2: Identify and Acknowledge Strengths

Identify the strengths of the organization and acknowledge these. Most organizations don't spend any time recognizing their strengths. As an example, your organization could state some of the following:

- We are the best community organizers in our state. We've created neighborhood organizations and associations. We are far ahead of all the other communities.
- We train others.
- We bring projects in under budget.
- We bring projects in on time.

Sometimes things work and sometimes they fail. But the important thing is to identify and acknowledge the strength. As with anything, be realistic as well as thorough.

Step 3: Determine the Mission or Purpose

Determine and write the purpose or mission, not only of your organization, but also of the project. Once you have the purpose of your organization then you have the purpose of the project. Look carefully to see how these fit together. Do they fit with the purpose and mission of the larger organization? Do these plans work in concert or are they in conflict?

Step 4: Set Goals and Objectives

Outlining the goals and objectives of the project is a must. The old saying is "if you don't know where you are going then you can take any path to get there." This is a recipe for GIS disaster.

Establish deadlines. The point of a deadline is to have a consequence at the end. In order to meet your objectives you must have deadlines.

It is important for you to determine what needs to be done to complete the project on time. One way to do that is to display your goals up on the wall of your ofice.

One of the most important traits for any individual and any organization is the ability to say 'No'. One of the reasons why major GIS projects get delayed, miss scheduled deadlines and come in over budget is because additions are made to the GIS project scope. New projects and new applications are requested and the administrators of the GIS is unable to say no. They say 'sure' and, as a result, not only do they not get the GIS done but when you don't meet your deadline, the credibility of the project people and of the organization is reduced.

Step 5: Visualize Success

Show pictures of your successful project. Architects and planners have always done this. It helps people see the successful completion of the project. For a GIS system, put the analysis, mock-ups of the analysis, and maps on the wall of the office for all to see. Show the dates of when you are going to achieve these and how the data will be utilized for the organization.

Step 6: Take Action

Visualizing. Organizing. Clearing off your desk. None of these matter unless you take action. The root word of 'satisfaction' is 'action". Visualizing is not enough. Good ideas are not enough. You and your organization must act on the opportunities that are put in front of you as well as create your own opportunities.

It is usually impossible to complete a major project by yourself. In our environment of declining resources, many are competing with several organizations for just a few dollars. You have to ask others for their support and assistance to get your project done. You can't do it on your own. The more people that help you with the project the greater the likelihood of your success. Ask others to participate. Once you have established the greater goal and once you say, "We're going to get this done by this date", it is amazing how many people will try to help you obtain your goal.

Step 7: Get Feedback

Once you start on a path, you need some feedback about the actions that you have taken. You have to know if you're going in the right direction and doing the right things. You've planned. You've taken action. You start walking down the path. Feedback guides you in the right direction.

Planning is really easy. It's implementing the plan that is tough. Part of the problem of implementing is this problem with feedback. It doesn't always happen automatically. You have to ask for it.

When you are asking for feedback, you not only ask at the top of the organization, you ask at the bottom of the organization. The people who are at the lower end of the organizational ladder are doing the production and the analysis work that you will need to achieve your goal. These people are frequently passed over. These are the ones who frequently have the best ideas.

Part of your review must include checking to see if you had the right ideas in the first place. You must ask "Was it an appropriate goal? Was it a realistic deadline?"

Step 8: Persevere

Calvin Coolidge said "Nothing in the world can take the place of persistence. Talent will not; nothing is more common than unsuccessful men with talent. Genius will not; unrewarded genius is almost a proverb. Education will not; the world is full of educated derelicts. Persistence and determination alone are omnipotent." There is a similar quote attributed to Winston Churchill, which says "Never give up. Never, never give up."

As you persevere, it is important to review the goals and objectives to make sure that they fit and are still appropriate. Review the mission to assure that it fits together with the goals and objectives.

Step 9: Reap the Rewards

After you've done all of the work for the GIS project, reap the rewards of your success. Celebrate the successes. Celebrate realizing the smaller, individual steps that were taken to reach the goal.

Step 10: Share the Success

Once you have it, you've got to share it. In order to have something, you have to give it away. Share your experience with others. Present papers. Give talks. Write articles for magazines. Help others in your neighboring communities to achieve what they are trying to achieve. Thank the people who helped you meet your goal because you couldn't have done it by yourself. Reward the people in the organization who helped you obtain your goals. One of the saddest things in an organization is when the leader takes all the credit.

Conclusion

The material presented in this paper has been written in brief outline form. Along with other GIS specific suggestions, the material outlined in this paper will help you and your organization implement a successful GIS project that will be good for your organization as well as good for your community.

Concurrent Session 17

Techniques - Integrated database management

Creating a Digital Natural Resource Database

Technological Advancement in Forest Inventory

Managing the House that GIS Builds

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Creating a Digital Natural Resource Database: The Results of the 1:250 000 Baseline Thematic Mapping Prototype

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Abstract

A Baseline Thematic Map is a natural resource database derived from processing satellite imagery in conjunction with digital topographic data. The database is comprised of three themes: present land use, ground cover and topographic features. Two scales are proposed corresponding to the two available digital topographic data sets, 1:250 000 and 1:20 000. Both scales utilize Landsat TM satellite image data. The motivation for this work is the development of an efficient, cost effective method of providing GIS compatible natural resource map data in a standardized form across the province.

This paper presents an overview of the methodology and results of the 1:250 000 scale Baseline Thematic Mapping prototype. A GIS compatible database covering 16 000 square kilometres was constructed that included: 8 land use types, 19 ground cover classes and four topographic attributes. Technical requirements of Baseline Thematic Mapping are presented, with the objective of implementing this concept as an operational mapping program.

NTS mapsheet 82 E (Penticton) located in the southern interior was the area chosen for the 1:250 000 prototype work. Input data consisted of a Landsat TM image (digital and hardcopy transparency) acquired August 22, 1987, the digital base map for NTS mapsheet 82 E, ground truth collected by two persons over four weeks in 1988 and 1990 and some existing map information.

Introduction

The Baseline Thematic Mapping (BTM) prototype was initiated to define a methodology for extracting thematic information from satellite image data and digital topographic data. The thematic information is intended to populate a natural resource database comprised of three themes: present land use, ground cover, and topographic features. The complete database would provide consistent, province-wide coverage in a format compatible with commercial geographic information systems (GIS). The primary motivation for this work is to satisfy the increasing demand for natural resource information that is GIS compatible, comprehensive, up-to-date, and cost effective.

The approach taken in establishing the BTM methodology was a comprehensive evaluation of the potential for information extraction from satellite imagery, analyzed in conjunction with digital topographic data. This paper reports on the methodology developed for 1:250 000 scale mapping. The area of interest is National Topographic Series (NTS) mapsheet 82 E covering 16 000 square km in the southern Okanagan Valley. The methods employed in creating each of the three themes comprising the BTM database are summarized below.

The present land use theme was derived from a manual interpretation of a colour transparency of the satellite image. The land use interpretation was accomplished by projecting the satellite image onto a paper plot of the digital 1:250 000 mapsheet. The interpretation was then digitized into this digital file and the attributes loaded into the database.

The ground cover theme was derived from a supervised classification of the digital satellite image data. Other required image processing included 2-D rectification, image mosaicking, data volume reduction, context filtering and error assessment. The image was stratified before classification to strengthen the spectral classification process. Eleven broad strata were defined, based on present land use, topographic or ecologic zone and illumination considerations. Classification accuracy was assessed by using ground truth to construct error matrices for the ground cover classes of interest. The raw classification was context filtered to reduce the complexity in a cartographically acceptable manner. Context filtering amalgamates small areas with neighbouring classes based on user supplied criteria. The ground cover theme was then transferred to the GIS domain for further editing and inclusion in the database.

The digital topographic information is in the form of scanned contour lines. The published paper 1:250 000 NTS mapsheets have been scanned and are available from Energy, Mines and Resources Canada as digital files. A digital elevation model (DEM) was produced from this data as a regular grid (100 m spacing) of elevation, slope and aspect values.

The following is a summary of the schema for the three themes of the prototype Baseline Thematic Map Database for NTS mapsheet 82 E.

BTM 1:250 000 Prototype Schema

Landuse
Urban
Agriculture
Rangeland
Logging Clear-cuts
Forest
Alpine
Rock
Water

Ground Cover
- Agriculture
  - Orchard and Vineyards
  - Irrigated Crops
  - Forage and/or Grazing and/or Shrub covered
- Rangeland
  - Range (steppe and savannah)
  - Sparsely Forested Range
- Logging Clear-cuts
  - Disturbed Soil, Rock and Slash
  - Herb and Grasses
  - Shrub and Deciduous
  - Regeneration, Shrub and Herb Mixtures
  - Immature Coniferous (< 10 m height)
  - Coniferous Forest (this class because some areas of many small clear-cuts were mapped as a single land use polygon, thus they included mature coniferous forest)
- Forest
  - Wetlands and Meadows
  - Sparse (less than 25 % canopy closure)
  - Open (26 to 65 % canopy closure)
  - Dense (more than 66 % canopy closure)
- Alpine
  - Rock
  - Krummholz
  - Alpine Meadow
  - Subalpine Forest

Topographic Features
- Elevation (average)
- Slope (average)
- Aspect (dominant)
- Watershed

Present Landuse Methodology

Landsat thematic mapper (TM) image data were used for both this theme and the ground cover theme. The present land use was derived from a manual interpretation of a colour transparency hardcopy (TM bands 5, 4 and 3 displayed as red, green and blue). The imagery was acquired on August 22, 1987 and included the area covered by the 1:250 000 Penticton NTS mapsheet (82 E). This task was accomplished under contract.

Classification Scheme

A modified version of the schema for Land Use Classification in British Columbia (Sawicki and Runka 1986) was used to categorize the present land use activities identifiable in the interpretation of the transparencies. Generally, the highest level of the land activity classification hierarchy was used, with the inclusion of some secondary and tertiary classes where these were clearly differentiable. No fourth level classes were identified although four additional modified classes were added. The level of generalization was appropriate for the 1:250 000 output scale. In some areas, particularly agricultural areas, the level of detail interpretable from the image data would allow for lower level classes to be included. In other areas, the level of detail interpreted was limited to that suitable for inclusion in 1:250 000 scale thematic map output.

Database Creation and Evaluation

The present land use was interpreted from the satellite image transparency using a PROCOM projection device. This device projects the transparency onto a paper base map and the features of interest are simply drawn directly onto the map. In this case, the base map was a plot at 1:100 000 of the 1:250 000 digital file for NTS mapsheet 82 E. The interpreted present land use features were then digitized into the digital map file for 82 E. Attribute data (polygon numbers and classification codes) for each polygon were included in a dBase III PLUS database.

The estimated map accuracy for the eight general classes was approximately 75 per cent before editing and approximately 85 per cent after editing. This estimate was arrived at by inspection of this theme overlaid on enhanced imagery and by reference to topographic maps and local knowledge of the area.

Ground Cover Methodology

Ground cover thematic information was derived from digital Landsat TM imagery of the same date as the transparency hardcopy. These data were received as a systematic georeferenced full scene covering an area measuring 184 km by 172 km.

Digital image analysis procedures were applied to the image data including geocoding, mosaicking, and digital classification for ground cover. Although seven bands were available for this digital analysis, only TM bands 2, 3, 4 and 5 were utilized in the classification procedure.

Georeferencing

Two dimensional rectification of Landsat image data involves the identification of ground control points on the image which correspond to features on the associated paper or digital map. Forty-five control points were identified in the image data and on the sixteen 1:50 000 paper map sheets that cover the 1:250 000 sheet. The image was then warped to fit the map, with the RMS positional error estimated to be 75 metres in both the x and y directions.

At this stage, the pixel size was resampled from 30 metres to 25 metres (pixel = picture element; a single grid cell of the scanned image). This was done because 25 m is a standard size for geocoded Landsat TM imagery and for ease of transfer to and from GIS files, since 25m nests evenly within a 100 m interval.

The availability of the digital elevation model allowed for the explicit correction of relief displacement. This correction was not applied to the 1:250 000 prototype image data set because relief displacement was not a significant concern at this small scale, with maximum expected displacements of approximately 1 mm at 1:250 000.

The issue of relief displacement has been investigated utilizing 1:20 000 TRIM (Terrain Resource Information Management) digital elevation models. The software development is complete tests confirm the usefulness of the technique, with accuracies of ±30 m (one pixel). In high relief areas, with relief greater than 1000 m and at large mapping scales, scales larger than 1:100 000, this approach and the associated processing is justified. This is particularly important in British Columbia when producing thematic mapping from Landsat TM data at 1:20 000 scale. At smaller scales, such as 1:250 000 or where there is little relief, the two-dimensional correction is adequate.

Mosaicking

Complete coverage of the entire 1:250 000 NTS map sheet (82 E Penticton) used for the prototype required image data from more than one Landsat TM scene. A Landsat scene is equal in area to about two 1:250 000 sheets, but the angular tracking of the satellite as it acquired the image scene resulted in the southeast corner of the map area (82 E) being excluded from the main digital image. When ordering image data the user can specify location the along swath in a north-south direction but the east-west location is constrained by the satellite's orbit.

Additional image data, from July and August 1985, for that corner was incorporated into the larger digital image through image-to-image registration and mosaicking. The resulting image covered the entire prototype map area with little noticeable difference in the radiometric balance between the portions of the mosaicked image originating from different scenes. Because of this and because of the small area covered by the additional imagery no radiometric correction was performed. In this case, the area was very small, covering less than 5 per cent of the total mapped area, and the ground cover was primarily forested with a few small logging clearcuts. The additional processing involved in selecting separate training sites for cover classes and resolving any inconsistencies between the statistics generated for the main image and the small corner area was not justified in this case.

Data Volume Reduction

A major consideration in dealing with the digital image data was managing the large data volume. At full resolution, using the 25 m by 25 m pixels, each band is a 28 Mbyte file. For each operation performed in the digital analysis domain, one or more files of equal size would be generated, resulting in a tremendous demand on the physical storage capacity of the PC-based image analysis system. In addition, the time involved in processing files of that size would be prohibitive, even for relatively simple operations. Under these circumstances, a test was performed to compare classification results using the full resolution of the image data, using the 25 m by 25 m pixel size, with classification results using imagery resampled to a 100 m by 100 m pixel size. The data volume was reduced by a factor of sixteen (28 Mbyte input to 1.8 Mbyte output) through this procedure.

The test was performed on a small data sample for which good ground truth was available to facilitate accuracy assessment. This sample was a composite image of five locations consisting primarily of logging clear cuts. Both the 25m full resolution image and the 100 m resampled version of the same image were classified using the Bayes Maximum Likelihood classification algorithm with bands 5, 4, and 2 as input. The resulting classified images were compared to the corresponding truth images for the area. Context filtering was applied to each of the classified images to simulate the results which would be required in completing the classification of the image covering the entire area.

The error assessment routine involves a pixel by pixel comparison of a truth image versus a classified image. The resulting matrix contains both the user's and producer's accuracies on a class-by-class basis. Comparisons of overall mapping accuracy for pre- and post-context filtered versions actually show a slight improvement in classification accuracy from 79% to 83%. The results of the data reduction tests indicated no meaningful loss of classification accuracy in reducing the data from the 25 metre full resolution pixel size to the 100 metre pixel size. The use of the resampled imagery was justified in this manner and further processing of the 1:250 000 prototype data set proceeded using the reduced data set.

Digital Image Classification

Classification of digital satellite imagery requires the delineation of training sites to be used for the generation of classification statistics. The classification may be performed on the full image, or may be restricted to a particular area of interest. The ground cover classification for the BTM 1:250 000 prototype consisted of a number of separate classifications. The classification effort was stratified by land use, ecological zone and illumination conditions. This was done to make the spectral classification process more robust by limiting the number of variables affecting the signatures of the ground cover. Pre-classification stratification also made error assessment simpler because of the limited number of ground cover types.

The detailed land use codes produced in the present landuse interpretation were generalized into eight levels for transfer from the GIS to the image analysis environment. The eight strata covered alpine, forested, logging clear-cuts, rangeland, agriculture, urban or commercial, water and rock. Five of the eight bit-maps were used as masks in the classification procedure, with rock, urban/commercial and water not classified in the ground cover processing. A similar sequence of steps was used to perform the classification for each strata under the appropriate area, with some additional refinements incorporated for the forest strata.

Training Site Delineation, Signature Generation and Classification

Training sites were identified for the logging clearcuts from detailed ground truth information collected during September 1988, corresponding to the same time of year that the satellite image data were acquired in late August 1987. Eighteen signatures were generated from TM bands 2, 4 and 5 for classes including bare soil or rock, slash areas, herbs, grass, shrubs, deciduous and coniferous regeneration ground cover types.

Training sites and signature generation for the rangeland and alpine strata were determined by identifying broad cover types of the digital image in the area under the appropriate mask. These classes were based on colour, brightness and, to some degree, by topography. Six rangeland signatures and four alpine signatures were generated from these training sites.

The training sites for agricultural classes were defined using class information from existing 1:20 000 scale present land use mapping digital files for parts of the area, which were derived from photo interpretation and intensive field work, and from ground truth of a more general nature collected through field work for this project. Signatures were produced for four agricultural classes.

For the forest strata, ground truth was determined from Ministry of Forests (MOF) 1:20 000 digital forest cover maps. These digital files contain detailed information such as species, crown closure, age class, height class, etc.. One 1:250 000 map includes one hundred 1:20 000 maps. Nine map files were used for ground truth. Treatment of the forest strata is addressed in greater detail under Forest Classificaiton Stratification.

Supervised classification was performed for each of these five strata, with TM bands 2, 4, and 5 input for classification of the alpine, logging clearcuts and rangeland strata, while the agriculture and forest classifications also included TM band 3. The Maximum Likelihood classification algorithm was used for all classifications.

Forest Classification Stratification

The forest cover mask overlays a substantial amount of the source imagery, an estimated to be 70 per cent, and contains a wide variety of forest types. In an attempt to produce a more accurate classification of the forest types, the overall forest cover area was stratified based on elevation and illumination as follows:

- below 1250 metres, designated as low;
- above 1250 and below 1870 metres, designated high;
- above 1870 metres, designated as subalpine;
- high illumination, designated as sunny; and
- low illumination, designated as shady.

The lower elevation break corresponds to the interior Douglas fir to montane spruce biogeoclimatic zone change for the western part of the map sheet.

Relative solar illumination was calculated for the sun position at the time of image acquisition. At mid-morning (Landsat imagery is always acquired at the same time for any one spot on the globe, about 10:30 for southern B.C.), the sun is in the southeast, specifically at an elevation of 47 degrees and an azimuth of 147 degrees for August 22, 1987. The sunshaded image, appearing much like a shaded relief map, did not determine cast shadow areas but shadows represented less than 5 % of the total area for this summertime acquisition date. The resultant sunshaded image was displayed along with two other bands of TM imagery. The sunny/shady threshold of the sunshaded image was interactively manipulated to determine what illumination threshold would mimic the obvious illumination differences visible in the imagery. These stratifications resulted in six areas within the forested area:

Forested - High and Sunny;
Forested - Low and Sunny;
Forested - High and Shady;
Forested - Low and Shady;
Forested - Subalpine and Sunny; and
Forested - Subalpine and Shady.

The six strata were each classified into three canopy closure classes and a wetlands/meadows class; wetlands and meadows were only extensive in the subalpine and high elevation strata. The canopy closure classes were: Sparse (less than 25%), Open (greater than 26% and less than 65%), and Dense (greater than 66%).

Context Filtering, Modal Filtering and Class Amalgamation

The requirements of output at 1:250 000 scale are such that the reduction of the complexity of the classified image is necessary. This is both to produce a cartographically acceptable presentation and to accommodate possible limits in the GIS environment in which the thematic database will reside. Simplification of the classification output was achieved through post-classification processing using the context filtering routine developed in-house. Context filtering introduces the concepts of adjacency, similarity between classes, and minimum polygon size. Small areas are merged or not merged with a neighbouring class based on their similarity, length of shared boundary and area. This capability allows a great deal of control over the generalization of the raw classification and produces a cartographically acceptable final map.

Polygons defined in the context filtering process were retained at a minimum size suitable for presentation at the 1:250 000 output product scale. This was set at 200 hectares for the 1:250 000 prototype, which equals 200 pixels for the 100 by 100 metre pixels. For the clearcuts, the minimum size was set to a smaller size with some individual clearcuts being only 30 hectares. It was not considered desirable to merge these areas into the surrounding forest areas because clearcuts are so highly differentiated from the surrounding forest. Subsequent to the post-classification processing in the image analysis domain, the classified image was transferred to the GIS for further processing.

The highly detailed result of the classification and context filtering procedures produces some very convoluted boundaries between class polygons. These were smoothed to reflect the level of detail appropriate to the 1:250 000 scale of interest. This was accomplished by applying a 3 x 3 or 5 x 5 modal filter to the output files.

The complexity of the classification schema was reduced by amalgamating selected classes, through the application of an appropriate look-up table. This process resulted in nineteen final ground cover classes.

Error assessment

After final class amalgamation and field validation of the prototype, error assessment matrices were produced for all classifications. Overall classification accuracy results for the five classified strata are summarized below:

LAND USE	Number of Ground Cover Classes	Overall Thematic Mapping Accuracy
Agriculture	3	89 %
Rangeland	2	84 %
Forest	4	84 %
Logging Clear-cuts	6	86 %
Alpine	4	97 % *

(* Note: Overall thematic mapping accuracy for the Alpine area was assessed for 2 classes only due to accessibility in field validation.)

Topographic Features

The topographic features for BTM are derived from digital topographic data. The National Topographic Series (NTS) 1:250 000 maps have been scanned to generate digital files. Coverage is available for the entire province. The digital file for 82 E, the prototype area, was obtained and used for the base map and also to generate a digital elevation model (DEM) for the area.

Aside from the use of the DEM for pre-classification stratification, average elevation, slope and aspect attributes were allocated to every ground cover polygon. Additional topographic information has been included in the BTM database in the form of major and minor watersheds, digitized from Ministry of Environment, Water Management Branch records.

It was found that scanned contour lines alone do not provide a well-controlled model of the topography because all of the information is, of course, restricted to certain elevations which depend on the contour interval. Data restructuring has been undertaken, including the creation of a DEM based on a subset of the contour line points, interpolated mass points and hydrographic breaklines. This work was performed under contract for a different 1:250 000 mapsheet than that of the prototype. A significant improvement in the resulting digital elevation model is achieved through this process. Specifications have been developed for the application of this data restructuring for all of the 84 1:250 000 map files covering B.C. (Ministry of Crown Lands, 1990).

GIS Integration

The completed ground cover classification was transferred to the GIS. Polygons were defined based on the ground cover classification, and attributes were attached in the associated database. Although context filtering results in a single ground cover attribute for each polygon, the proportions of the four main ground cover types making up the polygons could be extracted from the pre-context filtered classified image. This was accomplished by overlay processing within the GIS and the four predominant ground cover classes were included in the database, expressed as percentages.

The composite number of polygons for the various strata covering the entire map area is 2345. This is in keeping with the maximum number of polygons manageable by some GIS, and is also intended to satisfy cartographic standards in presentation of the map information at the 1:250 000 output scale. Additional polygons would introduce a high level of confusion for users.

1:250 000 Prototype Results

The 1:250 000 Baseline Thematic Mapping prototype is comprised of three themes, present landuse, ground cover and topographic features. The product consists of two digital files; one graphic and one database. The database attributes include land use, ground cover, proportions of unfiltered ground cover classes, average elevation and slope, dominant aspect and watershed. These attributes are listed in Table 1. The landuse theme included 1368 polygons for the eight general land use classes, the entire 1:250 000 mapsheet area. Ground cover classification produced 2345 polygons the prototype area.

Table 1. Baseline Thematic Mapping Database Attributes

Polygon #	346
Present Land Use	Logging Clear-cut
Ground Cover	Disturbed Soil
Pre-Context Filter Ground Cover Proportions	70% Soil 22% Herbs 6% Shrubs
Average Elevation	1150 Metres
Average Slope	12 %
Dominate Aspect	South Southwest
Watershed	Mission Creek

Conclusions

The derivation of a 1:250 000 scale digital natural resource thematic database from the analysis of Landsat TM imagery and digital topographic data has been demonstrated. The product is called a Baseline Thematic Map and is comprised of three themes, land use, ground cover and topographic features. This methodology can be an efficient, cost effective approach to providing GIS compatible natural resource map data in a standardized form. Based on this methodology, it is feasible to propose an operational program to produce Baseline Thematic Mapping at 1:250 000 for the entire province.

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Technological Advancements in Forest Inventory

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Abstract

To efficiently manage its forest resource, both environmentally and economically, Fletcher Challenge Canada Ltd. has been using the latest technological advances to aid in forest inventory. Fletcher Challenge Timberlands Department, in conjunction with DataSpan/UGSL, have developed an automated process to digitize attributed forest polygon classifications from orthophotos derived from high elevation (1:60 000 - 1:70 000) TRIM imagery. The automated digitization process involves scanning of the orthophoto map, editing, and digital mosaicing to provide a topologically clean, highly accurate GIS digital product. The techniques used to derive this product allow Fletcher Challenge Canada Ltd. to appreciate a cost saving at each level of the project.

The final digital product is being used to aid in field sampling intensity planning, preliminary inventory analysis, forest classification field work verification, forest classification finalization, annual allowable cut (AAC) calculations, logging development plans, cut block layouts, and road designs. Such flexibility is available only because the digital data is accurate enough to be used at scales suitable for both operational and inventory mapping.

Background

Fletcher Challenge Canada Ltd. wood products is composed of three corporate entities: Coast Wood Products; Northern Interior Wood Products and South Interior Wood Products. To best suit their needs, each of these corporate entities have chosen their own Geographic Information System (GIS). Based at Fletcher Challenge Headquarters, the Timberlands Department presently compiles forest inventory and operational mapping for Fletcher Challenge Canada's holdings within British Columbia.

DataSpan/UGSL is a joint venture between DataSpan Technology Inc. of Alberta and Underhill Geographic Systems Ltd. (UGSL) of British Columbia. For the past six years, DataSpan have owned and operated the highest resolution service bureau scanner in North America. UGSL is a GIS service bureau providing data conversion, custom software, and project management for industry and various levels of the public sector.

Together, Fletcher Challenge Timberlands Department and DataSpan/UGSL have worked on the Ospika River project, a 700 000 hectare digital forest inventory project in the MacKenzie Timber Supply Area (TSA) of North Central British Columbia.

Introduction

Accurate, cost effective field inventory and operational mapping must be carried out in many stages. The first step in this mapping process involved the production of 1:20 000 rectified orthophotography, with a stereomate, from high elevation TRIM aerial photography (1:60 000 to 1:70 000). Forest cover polygons and attribute information, drainage, roads, and helipads were typed directly onto the 1:20 000 orthophotos. This information was then scanned directly from each individual orthomap. The digital information from each orthomap was edge tied and any source document discrepancies were highlighted in red on a digital test plot. The Timberlands Department made the necessary modifications to the highlighted areas manually, utilizing the original orthophotos as reference. DataSpan/UGSL incorporated these modifications and produced a GIS-ready digital product. The Timberlands Department field rectified the digital data, and subsequently is able to use this product for many planning functions both in the field and the office.

Drawing on the experience attained during the project, this paper will justify the methodology used to derive the final product, both in financial and mapping terms.

Forest Inventory Objectives

Throughout the project Fletcher Challenge Canada Ltd. has maintained the following objectives for their mapping products:

- To update the existing land and data information base to a level necessary to determine a Long Range Sustained Yield (LRSY) for the TSA and for each supply block (approximately 16) within the TSA;

- To evaluate the effects of long term deferrals/withdrawals on timber supply to existing mills (maintenance of cut);

- To provide stratum based information for longer term strategic planning purposes with sufficient detail necessary for operational planning purposes as a supplement to short term operational/cutting permit cruising;

- To provide inventory tree quality information of sufficient detail not only for existing mill supply forecasts, but also for future mill improvement and new facility construction; and,

- To provide a preliminary analysis of other resource values currently existing in the TSA, and to develop a long term resource inventory program for data collection and assimilation.

Mapping Requirements

The three year goal of this field inventory is to complete a forest inventory analysis of the MacKenzie region, an area of over six million hectares. To allow the type of forest management analysis required, a GIS approach will be necessary.

Current MOF methodology requires 1:15 000 - 1:20 000 low elevation photos be made available for forest stratification and forest attribute labels. In the MacKenzie TSA, there was little or no current low level photography available and, due to weather conditions, obtaining full low level photo coverage would require up to three years and an estimated $750 000 to $1 000 000.

Traditionally, forest stratifications would be designated from the low level photography using the mechanical Kail plotting process. Current techniques of Kail plotting the low level photography forest classifications would require that the TRIM base map and the low level aerial triangulation, for photogrammetric transfer to TRIM mapping, be completed. The approximate cost of aerial triangulation alone, at $50 per model, is $1.8 million. In addition, based on studies done for the Provincial government, Kail plotting is not capable of meeting TRIM positional standards in BC, and therefore does not provide an acceptable product.

Instead, forest stratification and attribute labels were obtained from 1:20 000 orthophotos and subsequent stereomates utilizing a high quality mirror stereoscope with 3x power binoculars. The resultant base mapping and forest stratifications are in the government standard format and meet the positional accuracy required by the TRIM standards (see TRIM release 3.1). In general, Fletcher Challenge Canada Ltd. must fit into the MOF's long range goal of adopting the MOEP government standard and incorporating their forest cover, range and recreation Inventory Branch information with the Timber Harvesting Branch (ATLAS), Surveyor General Branch (Cadastre) and the Surveys and Resource Mapping Branch (TRIM base map) information.

Fletcher Challenge's Approach to Data Collection

Fletcher Challenge has been utilizing high elevation TRIM photographs to produce corporate inventory and operational mapping for the past ten years. Use of high elevation photography, in conjunction with photogrammetric stereoplotters, produced topographic and forest polygon mapping at a scale of 1:10 000 in the MacKenzie TSA. The resultant map met Fletcher Challenge Canada Ltd.'s standards in regards to polygon size, to the detail of label information, and to operational requirements.

Conclusions Related to the Data Collection Approach

Based on Fletcher Challenge Canada Ltd.'s past experience, several facts relating to the MacKenzie inventory have become evident:

- Low level photographs and the traditional procedures were both impractical in terms of cost and time frame constraints;
- High elevation TRIM photographs, as well as block aerial triangulation, were available over the entire MacKenzie TSA;
- Fletcher Challenge technology had demonstrated that forest stratification standards could be met utilizing 1:70 000 TRIM imagery;
- Limited in-house staffing required that contract photo-interpretation was necessary, which required the production of the 1:20 000 orthophoto and stereomates to utilize conventional photo interpretation;
- Cost for a controlled photogrammetric map-based product, produced from the TRIM imagery with TRIM control points was significantly less and made it possible to commence the project immediately in the summer of 1990; and,
- An orthophoto with a stereomate was required for stereoscopic viewing. This allowed classifiers to use present equipment and produce a base map and forest stratifications.

The greatest advantage of the orthophoto product is that the resulting classified orthophoto is capable of being directly digitized. Low level techniques require an interim step of photogrammetric transfer with its associated cost and editing.

In summary, the 1:70 000 high level aerial photography has the necessary resolution for classifiers to stratify the photos to meet corporate and Ministry of Forests specifications. Forest stratification from high level aerial photography was produced for approximately one third the cost of traditional low level photographic processes.

Methodology

Due to the need to provide a tremendous amount of stratification and preliminary attribute labels in the primary stages, orthophoto coverage would be obtained for approximately fifty percent of the area of priority. This was to assist in obtaining the ground sample plots to adequately sample stratum types within the supply blocks, specifically for those areas with the highest amount of merchantable timber.

The orthophotos with stereomates were then distributed to the contract forest classifiers. The orthophoto product was proven to have the necessary resolution to stratify and attach forest labels to the polygons. The polygons had an average size of 15 to 20 hectares, depending on the forest's productivity.

The classifiers have also interpreted planimetric detail which served as an interim base map until the final TRIM base map was available. This base map information was digitally separated from the forest cover overlay in the automated digitizing process.

Results of Data Collection

The source document for digital data conversion was an orthophoto map based on TRIM imagery, superimposed on a NAD83 UTM grid to facilitate digitizing and subsequent mosaicing of the polygons. The source document is, in essence, a highly accurate orthophoto-based thematic map, which can meet government specifications and address long term strategic operational planning.

Digital Data Conversion

Digital data conversion included scanning typed orthomaps (typing included forest cover polygons and attribute information, drainage, roads, helipads, etc.), separating this information into layers, mosaicing adjacent digital orthophoto files into seamless data sets and cropping these files into British Columbia Geographic System (BCGS) map sheets. To complete the digital conversion of this 700 000 hectare project area in the required two months, DataSpan\UGSL produced an average of 16 000 hectares of final product per working day.

Providing topologically correct data files requires comprehensive data validation and editing functions. The tools used to provide this volume of digital data can be isolated into the categories of project management, data conversion processes, and software. All phases of the project management were vital to provide expedient solutions, which the project team could support, to the technical problems that arose. DataSpan's high resolution scanner provided the required precise geometrical representation of the source data. The data editing process has been aided by the proprietary software developed by DataSpan in cooperation with the National and Alberta Research Councils.

The success of this project has highlighted several advantages of this digital data conversion system when used for forest inventory and operational mapping requirements. These advantages include delivery of topologically correct data files through a comprehensive data validation and editing system, exceptional data handling capabilities, and precise geometrical representation of source data.

Data Validation and Editing Capability

One of the most significant advantages of this data conversion system is the ability to provide topologically correct data files for uploading to a GIS.

To streamline the validation and editing of these large and complex data sets, several automatic software processes have been developed. These processes involve the removal of all spurs (undershoots and overshoots), checks to ensure nodes were mathematically correct, and the detection and flagging of source errors which can include unlabelled forest cover polygons, forest cover polygons with multiple labels, and incomplete line work. Utilizing specially developed software routines, spurs were removed automatically while improperly connected nodes and other similar problems were queued for interactive rectification on the graphics terminal. As required, source-related labelling and line work errors were highlighted on a check plot for review and modification. These unique software abilities ensured significant cost and time savings throughout the GIS loading and processing sequence.

Attribute Data Handling Capabilities

Within this conversion system, all forest polygons were mathematically linked to the appropriate attribute information through the use of an 'intelligent' geographic marker and related intelligent user data file system. The simplicity of this approach offered significant advantages over traditional techniques of linking each polygon to its attribute through a 'unique' polygon number. These advantages became evident when adjacent files needed to be mosaiced or a digital data segment was cropped out of a larger seamless data base. Utilizing the DataSpan/UGSL system, the potential complexities associated with duplicated polygon numbers, non-matching ASCII files, and other source and 'unique' polygon number errors were eliminated. These processes were completed quickly and efficiently by manipulating a series of 'intelligent' markers.

After all mosaicing and cropping operations were completed, the user data file was sequentially numbered and a polygon number associated with each marker in the graphics file. An ASCII file of polygon numbers and corresponding attribute data was also prepared. In this way the host GIS could build topology for future analytical processing.

The final process before delivery of the data was the generation of additional polygon attribute data in the format required. The polygon attribute data included polygon area, UTM position and UTM polygon number, a subset of UTM position. Fletcher Challenge Canada Ltd. can refer to any attribute or combinations thereof, in a digital or hard copy form, for planning and review purposes.

Geometrical Representation

One of the principal advantages of scanning the base information from the source document is the geometrical accuracy with which the line work is replicated. Utilizing these data conversion and editing techniques, the digital line work precisely overlays the original source document or its digital raster representation. This precision results in improved accuracy and validity of results (timber volume, AAC calculations, etc.), ease of uploading, and an overall development of confidence in the data set. In general, this scanning process eliminates the inconsistencies introduced by the human element in providing precise, clean digital data, and provides this superior product at a projected 30% lower cost.

The Final Deliverable

To this stage, the final deliverable was a prelabelled forest inventory BCGS mapsheet, which had not yet been ground-truthed. Ground-truthing verified that 85 to 95 % of the pre-labelling was valid. Fletcher Challenge Timberlands Department have had to re-address a maximum of 15% of the labels and a maximum 5% of the stratification line work.

Use of the Digital Data

Producing digital data early in the forest inventory allows for many additional updating and data generalization functions once compiled utilizing traditional laborious processes. As an on-going process, any data additions or deletions to forest cover polygon information are easily made by simply editing the intelligent user data file and the associated graphics file. Fletcher Challenge Canada Ltd. uses the prelabelled BCGS map sheet for:

- field sampling intensity planning;
- preliminary inventory analysis;
- forest classification field work verification; and,
- forest classification finalization.

The geometric accuracy of the data allows it to be used to in the same way that traditional operational mapping is used, namely for:

- annual allowable cut (AAC) calculations;
- logging development plans;
- cut block lay outs; and,
- road design.

Fletcher Challenge Canada Ltd. also uses the data at scales from 1:10 000 to1:50 000. The forest cover classifications were much too dense to be useful at 1:50 000. To produce a legible product at such small scales required data generalization. Using DataSpan\UGSL software, selected linework is deleted and selective topological building is performed to connect the remaining line work. Generalizing this level of mapping requires generalizing labels as well as line work. Label generalization often involves selecting a separate classification from those previously attributed to individual polygons. Digitally re-labelling only requires only simple graphic and ASCII file editing.

Conclusion

This project has proven that the described methodology of forest inventory and operational mapping more accurately and expediently produces easier to manipulate digital data. The cost associated with orthophoto collection is one third the cost of utilizing the traditional methodology to collect the forest stratification data. The cost savings do not end here; in fact, the cost of the automated digital data upload used is projected to be thirty percent less than the cost of manual digitization. This project has successfully demonstrated a more cost effective method of forest inventory.

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Managing the House That GIS Builds

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Abstract

The ability of modern computers to handle spatial information has stimulated the interests of many who felt themselves in danger of missing the technological information revolution. GIS gives surveyors, geographers, planners and natural resource managers the opportunity to use computers for the collection, management and manipulation of data for spatially-based decision making.

But GIS has a power, unlike many other computing applications, which has yet to be properly harnessed, a power which extends beyond its mere technical horizons. GIS breaks down barriers, barriers that in the spatial data arena have created separate disciplines, even professions. No longer can special spatial data management skills remain the specific preserve of particular professions.

To fully benefit from GIS, traditional data management processes must change; yet, historically, these processes have provided the foundation from which some special-purpose agencies have emerged. Proper application of GIS requires as much attention to the management and institutional issues as to the data to be successful.

This paper draws upon the experiences of a State-wide jurisdiction in building a pan-agency GIS; it describes many of the institutional and management issues faced, some of which were solved, and some which were not.

Municipal GIS Applications

Data Standards and Conversions

Digital Information Standards:
a Major Step in Developing a GIS

Automated Data Conversion:
Technology and Case Studies

Fast Track to Database Completion

Municipal case studies

Current and Future GIS Applications in the City of Halifax

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Digital Information Standards - A Major Step In Developing a Municipal GIS

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Abstract

Development of municipal GIS has progressed enough to benefit from the latest in digital mapping technology. As most of the information required to operate a municipality are referenced to a geographic location, the municipal GIS should provide flexibility and ease in the retrieval and integration of this information. The system should also be able to cope with an increasing demand for the integration of applicable digital data from different sources. So far, the limiting factor for the broader use of GIS in a municipal environment has been the lack of generic digital data standards and specifications. This paper describes issues related to the development of large scale digital specifications as applied to a municipal GIS for data capture, data management and data sharing.

Introduction

More than seventy percent of the information for day to day operations in a municipality are geo-referenced in some way. Examples of this information are parcels, roads, sewers, buildings, sidewalks, parks, schools, environment, drainage and waterworks (Liley, 1987). In addition, some municipalities maintain utility operations such as telephone, electricity and gas distribution networks which also need land-related information.

Although municipalities have been using computers for a long time, the development of Geographic Information System (GIS) applications has been very slow, as municipalities have not fully recognized the benefits of the integration of geo-based digital data in a computer system. Rather, they have been simply overlaying hard copy maps for planning and engineering works.

As GIS technology has matured, municipalities have realized the advantages of an integrated approach to the management of their land-related information. In the past ten years, a large number of municipalities, mostly in the United States (Los Angeles, Minneapolis, Houston and San Diego) and a few in Canada (Calgary, Toronto, Burnaby and Oak Bay) have made substantial investments in GIS (Aronoff, 1989). These systems are being used in municipal operations such as property management (parcel) and appraisal (parcel and building), licenses and permits, planning and design for subdivisions, transportation and route analysis, engineering work, inventories of water, sewer and electrical systems, and general and detailed land use planning.

Manual or digital integration of land-related data was in the past centred mostly on the needs of provincial agencies. This resulted in a lack of understanding of the benefits of data sharing between municipalities, provincial and federal agencies. Although limited studies and pilot projects were carried out within municipalities, there has been little effort in coordinating the needs of land-related information for the municipalities and the provincial government.

Presently, the need to exchange geo-based information between municipalities and provincial and federal agencies has grown rapidly. But data exchange, using a variety of non-standard exchange formats, is a difficult and sometimes an impossible task (Pearson and Gareau, 1986). Examples of this are when municipalities have to use land-related data from the Ministry of Environment, Statistics Canada, or topographic data from National Topographic series maps.

Data sharing will be even more difficult, since municipalities are seeking GIS solutions in an independent manner. Consequently, it is desirable to develop common standards and specifications, before municipalities are too heavily committed to incompatible endeavours.

The Future Trends in Land-Related Data Integration

There are two ways of integrating geo-based data in municipal applications. One is to make available data which are captured in one system to the users of other systems without manipulation or changes. An example of this is the use of soil or environment data for planning. The other is to utilize GIS technology developed for processing land-related information in the very fundamental operations of a municipality in an on-line fashion. Examples of this type of integration are GIS applications in licensing, building permits, route selection and engineering works.

The future of data integration will combine both these approaches. As the benefits of geo-based digital data have been recognized by the municipalities, they will be more in demand. At the same time, more and more distributed graphics and land-related attribute data will be created which will attract municipalities. Eventually, municipalities with advanced GIS technology will have to integrate other land-related data into their fundamental day to day operations such as planning and decision making. This trend will continue until more than ninety percent (90%) of municipal operations will require a GIS with proper data integration capability.

The Important Role of Standards and Specifications

The Ministry of Crown Lands (MoCL) has been given the mandate to develop a strategic plan for the management of land-related information in the province of British Columbia. One of the goals of this initiative is to provide a facility for the exchange and sharing of geo-based information. This mandate will provide the opportunity to look at the entire geographic referencing structure for the province, including local governments. It will also provide an overview of existing and future land-related information systems as an integral part of the B.C. Land Information System. The outcome will be a series of actions which should be taken to create an environment in which independent land-related systems could function as members of a larger team within the province-wide goals and objectives.

The basic principle of data sharing is to capture data within pre-developed standards and specifications. Standards are required for the collection, referencing and storage of land-related data. These standards and specifications should provide consistency in the quality of data collected with regards to accuracy, resolution, geo-referencing systems, and data capture rules. A catalogue of data sources, internally and externally, is also needed to facilitate search on-line data and also to prevent duplication in data collection.

Conclusion

Municipalities are becoming more involved in the application of GIS for their basic operations. Integration of geo-referenced data between municipalities, province and federal agencies is necessary for planning, engineering works and decision making. The cornerstone for a reliable and easy data integration process is the creation of standards and specifications for data capture which are developed and maintained by an inter-agency committee. Fortunately, this task has been completed in the province of British Columbia. The Geomatics series of specifications for 1:250 000, 1:20 000, 1:5 000/1:2 500 and 1:1 000/1:500 map scales comprehensively cover all aspects of land-related digital data collection.

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Automated GIS Data Conversion Technology with Case Studies

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Abstract

For the last five years the Automated Mapping and GIS market (AM/GIS) has anxiously awaited the arrival of automated data capture or scanning technology to speed the conversion of existing hardcopy maps and facilities drawings into intelligent data. This paper presents several case studies in which automated data capture technology has been successfully employed in the conversion of hardcopy documents into intelligent digital data for use on AM/FM and GIS systems. For each of these cases, a comparison is presented showing the quality improvements, time savings and cost savings resulting from the use of this technology.

Introduction

Modern scanning technology was introduced in the early 1980s. At first, it was hailed as a miracle solution that would magically turn data conversion into a totally automated process. Automatic raster to vector conversion and automatic character and symbol recognition promised to eliminate the expensive, labor-intensive aspects of conversion projects.

Unfortunately, these initial claims seemed inflated and 'scanning' technology began to conjure up images of hours at an edit station correcting 'automatically vectorized' drawings. Then unintelligent raster and incremental conversion systems were developed, but it was found they did not offer the analysis capabilities typically required by a Geographic Information System (GIS). Costs decreased, but at the same time, so did the intelligence, quality and value of the resulting systems.

These disappointments were caused by two understandable errors. First, scanning technology was incorrectly oversold as a cure-all. Second, and more importantly, scanning both provides and requires a whole new approach to conversion. Scanning is only one ingredient; many technologies must be effectively integrated to allow the entire operation to be successful. For example:

- Optical disk technology is necessary for storage and access to large amounts of grey scale image data;
- High speed dedicated processors are needed to provide efficient raster-to-vector conversions;
- Artificial intelligence techniques must be integrated to provide sophisticated line and symbol classification;
- High resolution interactive raster and vector graphic workstations must be employed for efficient interactive scrubbing, map registration, vector editing and attribute assignment;

- Local area networks (LANs) must connect numerous workstations to allow images and data to be easily accessed and transported between processors; and,
- All of these technologies must then be carefully integrated into a finely tuned, automated production management system.

In other words, for scanning to replace manual digitizing as a more effective means of GIS conversion, the development of an integrated Automated Data Conversion (ADC) process was required. By combining these technologies, it has been possible to significantly increase the quality of GIS conversions and, at the same time, reduce the amount of time required to complete a project, particularly a large, complex project.

Definitions

Because integrated ADC technology is so new, much of the terminology associated with it is not yet fully defined or consistently used. Therefore, before describing the various technologies and how they are integrated, it is important to first define some of the basic terms as they are used in this report.

GIS Conversion:

The compilation and digitization of a related and consistent set of data to produce the intelligent graphic and non-graphic information required to support a Geographic Information System.

Automated GIS Conversion:

The integration of a variety of appropriate technologies into the GIS conversion process resulting in improved quality, reduced project completion time and lower cost through the reduction of manual labor.

Scanning:

The process of converting a hardcopy document or map into a digital picture or image. The scanning operation produces unintelligent digital information called a raster image, which serves as the basis for an automated conversion process.

Raster Image:

A digital picture resulting from scanning a document. This raster image is composed of an array of dots, or pixels (picture elements). Each dot represents the level of darkness, or grey scale, of the original document at that location. Raster images typically range in resolution from 200 to 500 dots per inch and may represent either black and white (binary) or full grey scale images with up to 256 levels of grey. For instance, a grey scale image of a 24 inch by 24 inch map at 250 dots per inch produces 36 megabytes of data.

Raster to Vector Conversion:

The process of identifying pixels which represent line work or graphics, separating these pixels from the background and converting them to a connected vector representation. This vector representation allows graphic information to be easily manipulated, edited, attributed and stored and is a basic component of a GIS. The raster to vector conversion process may occur either in a batch process, which requires no human interaction, or in an interactive process, in which an operator simply points to lines to be vectorized on a workstation screen and the system automatically follows, or vectorizes, those lines.

Interactive (Vector over Raster) Editing

The use of a high resolution color graphics workstation to allow an operator to easily view vector graphics as an overlay on top of a grey scale image of a source document. This interactive editing station is a key ingredient in the automation of the conversion process, including vectorizing, attributing, land base correction, edge matching and data verification.

Orthophotograph:

An aerial photograph which has been corrected for geometric distortions. The resulting photograph is accurate to scale in both x- and y-directions and can be used as a photographic map of the area.

Artificial Intelligence:

The ability of a computer to make decisions which appear to require human reasoning. These decisions are made by applying probabilistic rules that represent a given 'knowledge base' corresponding to a particular situation. Each of these rules, depending on its degree of correlation to the situation, is given a different weight in the determination of an answer to a problem.

Edge Matching:

The comparison of pairs of common linear features along a specified map boundary to create a single, joined feature.

Layer:

A 'structure' within a data base which contains individual features, or a combination of features and networks, which are logically related or associated by information type. A GIS database may contain as many layers as the user requires. Layers may be identified by number, name and description.

Hardware Technologies

Critical to the creation of the automated conversion process has been the development and integration of several key hardware technologies. The most important of these are briefly reviewed below:

High Resolution Grey Scale Scanners:

The first step in the automated conversion process is the scanning of source documents. Since the entire ADC process relies on the manipulation of digital images of maps and other documents, it is extremely important to make sure that an accurate representation of the documents be captured during this initial phase of the project.

Most scanners consist of two basic components: a sensing device which detects the amount of light reflected from a point or group of points on a document, and a transport mechanism which causes the sensing device to move in relationship to the document.

Most scanners today utilize a charge-coupled device (CCD) as the sensing element and one of the following types of transport elements:

- continuous feed: the document is moved over the sensing device by pinch rollers;
- flat bed: the document is laid flat on a table and held constant as the sensing device is moved over it; or
- drum: the document is attached to a drum while the sensing device moves across the drum as the drum is rotated.

Drum scanners are typically both the most accurate and the most expensive, but are limited as to the size document they can handle, which depends on the circumference of the drum. Flatbed scanners are slightly less accurate and a little less expensive, and maximum document size is also limited to the size of the bed. Continuous feed devices are both the least expensive and the least accurate, and have the greatest flexibility in the size document they can handle, particularly in the document feed direction. Most scanners being purchased today are either continuous feed or drum type scanners.

Optical Disk Drives:

A 24 in by 24 in document scanned at 200 dots per inch with 256 levels of grey produces 25 megabytes of data. A project consisting of 1 000 such documents therefore requires 25 gigabytes of image storage. Because of this massive storage requirement and the need to have very rapid access to all of the drawings which comprise a project, 'write once-read many' (worm) optical disk technology has been critical to the development of the automated conversion process.

Optical disk drives utilize removable platters which can be taken out and replaced in much the same manner as floppy disks. Optical disk platters are available in two basic diameters: 12 centimeters and 12 inches. Each platter can hold from 300 megabytes up to 2.4 gigabytes, depending on the particular technology used, and these storage capabilities are continually on the increase. Each 2.4 gigabyte optical disk platter can therefore hold approximately 100 high resolution grey scale images. A project which consists of 1 000 drawings can be maintained on only 10 platters and, by utilizing multiple drives, or simply by switching platters as necessary, drawings from multiple projects each consisting of thousands of drawings, can be easily accessed, manipulated and archived by an operator at a workstation.

Interactive (Vector Over Raster) Workstations:

Automated data conversion technology relies on the ability to manipulate very high quality raster images of maps, as opposed to sheets of paper. An operator must also be able to display vector information created from a map, or other sources, as an overlay to a raster image of a document. Thus, the development and integration of very high resolution and high speed graphics workstations has been one of the most critical elements in the ADC development process.

New display systems have very large internal memories, from 5 to 16 megabytes or more, to allow high resolution grey scale images to be quickly displayed, panned to any location and zoomed into to magnify small numbers and symbols. These systems also allow full grey scale images to be displayed, permitting an operator to easily view documents with varying shades of grey, scanned aerial photography and digital satellite imagery, with overlays of vector data. This allows vector data from one source to be easily compared to raster data from another source and for these documents to be viewed simultaneously, one over the other, for very precise manipulation and registration.

High Speed Dedicated Processors:

The analysis and processing of images requires very complex operations to be performed on very large data sets, a 24 in by 24 in grey scale image can produce as much as 36 megabytes of data. To reduce the processing times of specialized operations such as feature extraction and raster to vector conversion, high speed arithmetic array processors are employed. These processors allow the complex mathematical transforms required for vectorization and classification to occur between 10 and 100 times faster than possible on conventional, general purpose CPUs. Without this type of processing power, it would be impractical to perform these operations in a high volume production environment in which thousands of documents are routinely converted.

Local Area Networks:

One of the key challenges involved in developing the ADC process has been adapting it to large volume production needs. Much of the work done by the major vendors of scanning and drawing conversion systems has been based on the one drawing per operator concept. In other words, they were designed with the idea that one person would perform all of the conversion functions required on a single document before moving on to the next document.

This is not a practical approach for a large volume operation. Multiple operators must be able to work within a smooth production flow on very large, complex projects. This means that documents must be able to move automatically from one operator/workstation to another. And this requires moving tremendous amounts of information at very high speeds. A single drawing, with its associated files, might easily represent 30 to 50 megabytes of data. Thus to move just 20 maps through a process involving five different workstations, or processes, in a day requires the rapid transfer of about five gigabytes of data. On a typical day, a large volume conversion process may move as many as 100 maps, or 25 gigabytes of information.

The advent of local area networking (LAN) and cluster technology has therefore been a critical element in the success of the ADC process. LANs allow data to be moved from one processor to another at speeds of up to 1 megabyte per second. This means a drawing, as well as all of the information associated with it, can be available at any one of many locations in less than 60 seconds.

This technology has also led to the clustering of data. Centralized magnetic and optical storage systems can now be used without sacrificing rapid access by large numbers of workstations. In an ADC process, the LAN becomes the backbone of the operation by acting as the electronic 'conveyor belt', routing each document to the appropriate process at the appropriate time. As a result, there is no longer a need to manually move sheets of paper through the production process, and the movement of every drawing can be automatically tracked and relayed by the system.

The Process

The traditional conversion process can be broken down into five basic steps:

1. Landbase conversion;
2. Review and compilation of source documents (scrubbing);
3. Registration of source documents to the landbase;
4. Digitization of graphic entities; and
5. Building of attribute database for graphic entities.

Two additional procedures are not steps but, in an automated conversion process, take place continuously throughout the process:

- Quality control of both graphic and non-graphic information; and,
- Project and document management for the entire project.

These steps are described in detail in the following subsections, along with information on how they are being automated through the use of new conversion technologies.

1: Digital Landbase Conversion

There have traditionally been three ways to create a digital landbase:

1: Digitize the landbase directly from an existing hardcopy source.

Although these maps may be readily available, may be at the proper scale and are only moderately expensive, many existing landbases were created with poor ground control and cartographic standards. Thus, these maps may be very inaccurate and individual sheets may not tie together.

2: Purchase an existing digital landbase from a source such as the USGS or ETAK.

This data is generally readily available and very inexpensive when compared to other alternatives. On the other hand, landbases from these sources are often at a fairly large scale (1:24 000 or 1:100 000), may not contain the information required, or may not be available for the required area.

3: Create a new digital landbase from recent stereo aerial photography.

While this is very current and accurate digital landbase data and can provide significant details, including such things as driveways, sidewalks, utility poles and individual trees, it is also the most expensive of the three alternatives. To create a digital landbase for a single county from stereo photogrammetry could cost several million dollars.

Now, by integrating scanning, raster to vector conversion and interactive editing workstations, a fourth alternative is being developed. It combines the digitization of existing source maps and the use of aerial photography to provide the accuracy of aerial photography at a significantly lower cost.

The original hardcopy landbase maps are scanned and converted to raster images. Then these raster images are processed through raster to vector conversion software to separate the linework from the background and to automati-

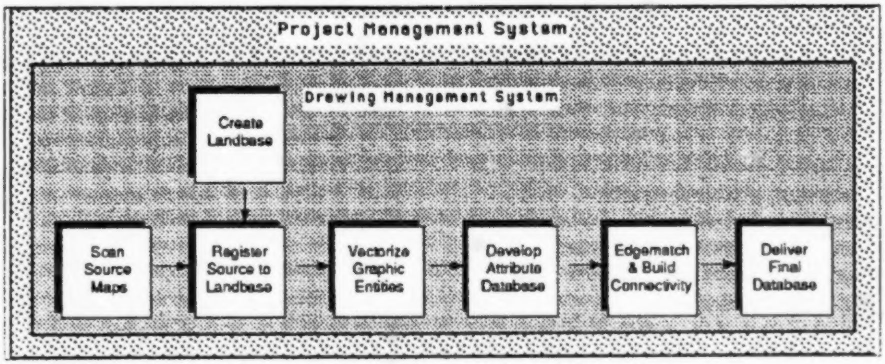
Project Management System
Drawing Management System
Create Landbase
Scan Source Maps
Register Source to Landbase
Vectorize Graphic Entities
Develop Attribute Database
Edgematch & Build Connectivity
Deliver Final Database

Figure 1: Model of the automated conversion process

cally digitize the graphics. The graphics are also divided into individual layers based on line width or line symbology. This information is then reviewed and edited at an interactive editing workstation. This process significantly automates the digitizing of the existing landbase by eliminating the manual digitizing process. The main problem that remains is that, as mentioned above, the original landbase may not accurately represent the real world.

To correct this inaccuracy, orthophotos are produced from aerial photographs of the area to be mapped. These orthophotos are then scanned to produce a grey scale raster image. The vectorized landbase information captured from the original hardcopy landbase is then displayed on top of the orthophoto at a graphics edit station. By indicating common points such as road intersections or property boundaries, the vector landbase can then be automatically warped to fit the orthophoto. In addition, any information which does not appear on the original landbase, such as new roads, may be easily updated.

This new alternative is less expensive because it uses automatic vectorization, and more accurate because it rectifies the landbase to current orthophotography.

2: Review and Compilation of Source Documents (Scrubbing)

This process, which ensures that all information to be converted to the GIS is up to date and accurate, varies significantly from one project to the next. It is also often a much larger task than anticipated because it is frequently discovered that records have not been kept as current as had been hoped. Each drawing must be reviewed and compared to other maps, work orders and property and equipment records, meaning thousands of documents must be organized and handled by dozens of people. Then, to complicate matters, construction and growth alter the information recorded even as it is being converted.

One way of dealing with this problem is to 'freeze' the records as of a specific date before conversion, perform the records updating and conversion, and then update the digital database with the modifications that occurred during this process. This makes the time required to complete the conversion critical: the quicker the conversion, the smaller the updating backlog.

Document management technology can significantly improve the management of and facilitate the handling of these thousands of documents. Each map or document is scanned and stored on optical disks before the scrubbing begins. Information about the type of document, the information contained on the document, and the geographic coordinates of the information contained on the document, are entered. The conversion system will then contain both a digital catalogue and a digital image of all documents, which may be on line and easily accessible to operators at interactive editing workstations.

Automated scheduling then routes specific documents to specific interactive editing workstations. This allows the scrubbing process to be managed through automated production control procedures. Changes or revisions are made through raster or vector editing techniques, rather than via laborious manual drafting. The status of the scrubbing process can be determined at any time and bottlenecks are easily identified and acted upon.

This approach is not usually economical when using a manual conversion system, since scanning all drawings before the scrubbing process simply constitutes an additional cost which is not readily recovered. On the other hand, if the entire conversion process is relying on automation through scanning technology, this approach implies no increased cost since all documents must be scanned and indexed as an initial step in the conversion process. By scanning the source documents before the scrubbing operation, the scrubbing has been integrated into the conversion process and automated the management, handling, manipulation and editing of the documents. Quality improves and both time and expense are saved. Moreover, post-conversion updating costs are also reduced, since the 'records freeze' period is far shorter.

3: Register Source Documents to the Landbase

By this point in the conversion process, a digital landbase has been created and the source documents have been reviewed and updated. The next step is to register these source documents to the digital landbase. Traditionally, the information from the source documents is manually warped to fit the digital landbase by redrafting or by cutting and pasting the source information on the landbase while making necessary adjustments to register the two data sets. This may require the source documents to be manually redrawn and is an extremely time consuming and relatively inaccurate operation.

Another approach has been to utilize control points, such as section corners or other benchmarks, to warp the source data to the digital landbase through the use of warping software. This eliminates the need for redrafting, but often provides insufficient registration since the warping required may vary significantly across a document and there is often limited control information available. For example, on one map, the upper left quadrant may need to be stretched in the x-direction, the lower left may need to be shrunk in x, while the upper and lower right quadrants may require independent distortions of x and y. This kind of rectification will require a minimum of nine control points, and optimally 15 to 25. As a result, it is often impossible to completely rectify the source documents to the landbase using this method.

A third approach, using scanning and interactive editing workstations, is now being developed. The corrected digital landbase is displayed as an overlay on top of a grey scale raster image of the source map. The operator can then easily detect any distortions between the digital landbase and the source map. The operator then identifies pairs of points, one on the vector landbase and one on the raster document, which should be tied together. After choosing several pairs, an interactive non-linear warping operation occurs and the results are viewed by the operator. To 'fine tune' the registration, the operator may continue entering points until a satisfactory registration is achieved. This operation results in a set of control points which are then used to warp the source map to exactly fit the digital landbase.

Through this process, it is possible to easily and precisely register the source map to an accurate landbase, even when the distortions are very random. More importantly, this does not require any redrafting of the source map to fit the digital base. And finally, it requires no known control points to be identified on the source documents.

4: Digitize Graphic Entities From Source Documents

Now the graphic information on the original source maps may be digitized.

Traditionally, this has meant laying each sheet on a large digitizing table, entering control points to register the map to the table, and manually tracing over each line, point, or symbol to be captured. This manual digitizing process is very time consuming, tedious and error prone. The quality of the digitizing is limited by the operator's ability to consistently follow the center of a line. This accuracy problem is further complicated by the fact that the operator has no opportunity to compare the accuracy of the digitizing to the original map until he or she plots a copy and performs an overlay of the document on a light table. At this point errors are identified and the graphics must be redigitized.

Scanning, raster to vector conversion, automatic layering and an interactive editing workstation significantly automate this laborious process. Source documents have already been scanned for scrubbing and land base registration and are now ready to be converted from raster information to vector information, which may occur in either a batch or an interactive mode. The batch process operates in two phases: first, the system automatically identifies graphics on the source map and separates them from the background image; then the centerlines of each graphic element are computed and converted to a set of connected vectors, or arcs. Artificial intelligence techniques are then used to automatically layer information into major categories, such as symbols, text, dashed lines, dotted lines or thick lines. This batch process provides the first level of intelligence to the data with no operator interaction and greatly increases the value of the data.

Raster to vector conversion may also be done at an interactive editing workstation by an operator, who simply points at the lines on the screen to be vectorized. This eliminates the tedious manual tracing operation required by manual digitizing.

The results of the raster to vector operation, either batch or interactive, is a set of graphic elements which are classified into major layers, such as text, symbols, hydrography, transportation or boundaries. This information can then be displayed on a interactive editing workstation on top of the grey scale image of the original source document.

The operator then groups graphic elements (arcs and points) into unique graphic entities, such as parcels, lakes, transmission lines, roads, etc. In this step, arcs which are required to represent more than one entity, such as both county and state boundaries, are not duplicated but simply linked to both entities. This interactive process can occur very rapidly by simply defining an entity and pointing to the graphic elements which are required to represent it.

The tedious manual digitizing operation is eliminated and the operator can easily compare the vector data to the original source document without generating a hardcopy plot. Graphic entities can be easily created and the duplication of graphics for coincident lines is eliminated. Most importantly, however, because automatic line following is utilized and because the operator has the ability to view the vector data on top of the original source map, digitizing errors are virtually eliminated.

5: Build an Attribute Database For Graphic Entities

It is now necessary to add intelligence to the graphic entities. For example, a graphic representation of a road may have been created, but information such as width, material, number of lanes, number of accidents and speed limit is necessary. Assuming this information is not already available in digital form from other existing databases, it must be manually keyed in. Information may first be manually entered on data entry forms or it may be keyed in directly from the original source map. This type of data entry operation is error prone and quality control is very tedious. Data is sometimes actually keyed in twice by independent operators to ensure quality.

Interactive vector over raster editing workstations can help here, too. When the attribute information appears directly on the original source map, this process can be automated as follows: an operator working at the interactive editing station enters an attribute definition loop in which the system displays the first graphic entity for which the attributes are to be entered; the operator is able to view the vectorized data on top of the original raster image, so all attributes which were indicated on the original map are easily visible. The system then prompts the operator for each of the required attributes. As the attributes are entered, they are displayed on the screen next to the original attributes to allow the data to be easily verified. Once the information has been approved, the system pans to the next graphic entity to be attributed.

There is no need to use data entry coding forms or to key in information directly from the original source maps. More importantly, the accuracy of the information is greatly improved, since it can be verified and approved on the screen. The result is significant time savings and improved data accuracy.

Quality Control of Graphic and Non-graphic Entities

After all of the graphic and non-graphic information has been entered, the accuracy and completeness of the data must be verified. This has traditionally involved numerous data validation steps, the plotting and overlaying of graphics information and the comparison of attribute data lists to original source documents. Depending on the complexity of the data and the quality of the scrubbing process, data validation, review and correction may consume as much as 25 to 35 percent of the total conversion time. In some cases, the customer even becomes involved in this process, reviewing data and often finding it necessary to return large portions for corrections.

Automated conversion can shrink the data verification process to less than ten percent of conversion time and eliminate the need for data to be returned for correction. This is due to the nature of the data creation process itself.

At each stage, scrubbing, landbase creation, graphic creation and attribute entry, two types of verification automatically occur as a result of the technology being used. First, an operator views the resulting data on top of the original raster image of the source document and, as each element is entered, it is compared to the original data and approved by the operator. Next, as the process continues, each operator must review the results of the previous operation.

Thus, quality control is no longer merely a final step; it is automatically built into the data throughout the conversion process. Of course, plots, listings and automated data validation checks are still used to double-check data quality, but the percentage of errors discovered during this final stage is drastically reduced, resulting in higher quality data, increased productivity and further time savings.

Project And Documentation Management For the Entire Project

This is the continuous process of managing the entire conversion project, from before the first map is identified, through the final verification and loading of all data. Thousands of documents are handled hundreds of times by dozens of people. Literally millions of operations must occur to create the final data. The complexity of the process is in direct proportion to the complexity of the database being created. Large conversion projects have historically taken several years, and must deal with having to maintain and update drawings during an extended time period. The management of this complex operation is therefore a key requirement to its success.

In a manual process, manual procedures must be utilized to keep track of each drawing and each process. It is difficult to maintain accountability, identify bottlenecks and keep up-to-date information on a project.

Utilizing the automation tools now available can simplify this management problem, although no large conversion project will ever be a trivial task. Since all drawings are handled as digital images through an automated drawing management system, instead of as sheets of paper, the documents do not deteriorate through handling, drawing images are easily accessed and document routing is automatically controlled. This drawing management system automatically provides individual drawings and project status information to an automated project management system, allowing project status reports and productivity reports to be automatically generated. And problems and bottlenecks are quickly identified and corrected.

Results and Applications

This unique, proprietary process can be beneficial for a wide variety of conversion applications, ranging from complex county parcel projects to soils, timber stands or wetlands mapping, to electric, gas, and water and sewer utilities conversion.

There are instances in which automated conversion is not the most appropriate way to proceed, however. Significantly, it is economics, and not technological limitations, which dictate when manual conversion might be more advantageous.

Because of the set-up required for the automated conversion process, it may not be cost effective to use this process to convert very low density maps, for example, a 40 in by 60 in contour map with a circle in each corner to scan. In this case, very little data is being captured, although the entire document would have to be scanned and processed through the entire system. Thus, it may be more economical to simply manually digitize the four contours on a digitizing table.

In general, the larger and more complex the project, and the denser the data, the greater the benefits derived from the use of this automated conversion technology. An example of how this technology is being utilized on a complex project is currently underway for the Southwest Florida Water Management District.

In this project, the information contained on more than 600 flood insurance rate maps (commonly referred to as FIRMs) and 200 floodway maps, which are produced by the Federal Emergency Management Agency (FEMA) must be integrated and converted. Combined, these cover an area equivalent to about 220 USGS quads, approximately 9 500 square miles, making this one of the largest and most complex projects of its kind. The FEMA/FIRM panels provide the only District-wide flood plain information available, essential data for the model being implemented, which will ultimately assist in the identification of lands to be purchased by the District for water resource protection.

In addition, District personnel frequently refer to FEMA maps to answer questions from the public regarding the location of floodplain boundaries. Automating the FEMA panels also will make it easier to update and improve the original maps, as well as permitting the creation of custom flood plain maps, and FEMA is interested in using address-matching strategies to automatically produce lists of homeowners living within flood-prone areas.

But most of these FEMA maps were made in the 1960s and '70s by a variety of contractors using a wide range of methodologies, with no horizontal control. This, plus the fact that they are being used for purposes never dreamed of by those who produced them, (flood insurance rate maps are being used as the basis for plotting wildlife habitat patterns and soil recharge rates) lay the foundation for a host of conversion difficulties:

- The maps are not simply black & white. They are composed of a number of shades of grey, which are used to delineate different flood zone information, such as 100 and 500 year flood zones.
- The data is derived from two separate maps. The FIRM maps contain flood zone information, and the information from the corresponding floodway maps must be precisely tied to these maps to form the resultant polygon data set.
- None of these maps have horizontal control information. This control must be derived from the corresponding 1:24 000 scale USGS quad sheets. Which further complicates matters, since
- The firm and floodway maps range in scale from 1:6 000 to 1:24 000, and the floodway maps do not usually correspond exactly to a portion of a quad sheet. This means that up to four USGS quad maps may be required to develop horizontal control for a single floodway map.

Ultimately, all of these maps must be precisely edge-matched to form continuous information and then cut into quad sheet-equivalent tiles for use on the District's ARC/INFO GIS.

Despite the fact that most of these maps are considered by many to be unscannable, the project is scheduled for completion in February, 1990. That represents a six-month turnaround time, half that specified by the Water District.

Parcel maps may also be successfully converted. Orange County, Florida needs to convert approximately 240 000 land ownership parcels contained on more than 1 750 parcel maps and encompassing about 500 square miles. Within each map, the parcels, lots, blocks, tie bars, hydrography, municipal boundaries, lot numbers and lot dimension features are being captured, layered and attributed. The entire project will be completed in only nine months. This project is the first major parcel mapping project in the nation to utilize this new technology, but certainly not the last.

In fact, another parcel project which fully utilizes the automated conversion process is just getting underway for the Northampton County, Pennsylvania GIS. This project involves the conversion of 673 parcel maps (100 000 panels) and 51 unrectified soils maps, covering approximately a 376 square mile area. Its purpose is to create a database using parcel graphic overlays, annotation sheets, orthophotos and unrectified soils maps, as well as data on the assessor's digital database. All parcel, soil survey, municipal and district boundaries must be scanned, captured, rectified and registered to the County's orthophoto base map and converted into 1:4 800 tiles. Then the data will be output in ARC/INFO Export format.

Other soil map conversion projects have also benefited from this integrated, automated approach. The USDA's Forest Service needed to convert approximately 10 000 soils information polygons comprising the Olympic National Forest, with associated attributes from 91 sheet maps at a scale of 1:288 000. The resulting data files contain the polygon along with the major soil, minor soil and slope associated with it. All data was then converted to Washington State plane coordinates and edge matched. The final product was a continuous, real world soils database for the entire Olympic National Forest of approximately 2 800 square miles. This data was delivered in MOSS format.

Finally, oil and gas, one of the first sectors to take advantage of this new technology, has particularly appropriate conversion needs. More than 1 000 7.5 and 15 minute USGS quadrangles were converted for a major oil company's corporate GIS. Four primary layers of data, hydrography, transportation, boundaries and points, were captured. Nineteen unique features were identified within these layers and the resulting data was fully topologically structured, converted to latitude and longitude coordinates and edge matched, regardless of the scale of the source maps. The result was an absolutely continuous real world database, covering approximately 80 000 square miles. Significantly, the project was completed in just ten months and fewer than two percent of the maps were found to contain even a single error.

Conclusions

On December 17, 1903 at Kitty Hawk, North Carolina, Wilbur and Orville Wright got their flying machine off the ground for the first time. Although Orville was aloft for only 12 seconds, this was the birth of aviation. Flying, however, did not become a more effective means of transportation than the automobile until several decades later, after an entire system of integrated technologies had sprung up around it.

Through the integration of these technologies, data is now of higher quality, people are more productive and projects are completed more quickly than anyone would have thought possible just a few years ago. But then again, in 1903, who would have ever thought Wilbur and Orville were not only getting us off the ground and across oceans in record time, but ultimately, all the way to the edges of the universe.

And now, through the creation of geographic information systems and automated conversion technology, we can improve the way we manage our small corner of that universe.

Appendix

Case Study #1

Automation of County Parcel Maps for the Orange County GIS

This project involved the conversion of more than 240 000 land ownership parcels contained on more than 1 750 parcel maps. The County encompasses approximately a 500 square mile area. Within each map, features such as parcels, lots, blocks, tie bars, hydrography, municipal boundaries, lot numbers, lot dimensions, etc., were captured, layered and attributed.

This was the first major parcel mapping project to use automated data conversion technology. As a result of this work, Orange County is experiencing better graphic quality and data accuracy than is typically produced by manual digitizing methods.

The Orange County GIS hardware includes DEC VAX computers, terminals, peripherals and GPX/II workstations located at four major locations. The large scale data processor is a VAX 8850 and is connected with five departmental Micro VAX 3600 computers, all interconnected with very high speed fiber optic links in a government-owned network. Many DEC GPX/II and VAXStation 2000 workstations are also connected to the network using the Ethernet and DECnet protocols. The network represents a distributed computing network with a central map/database on the VAX 8550 with more than 5 gigabytes of on-line disk. Software includes Geovision Corporation's AMS (Advanced Mapping System) and GIS products, McDonnell Douglas's GDS CADD software, ORACLE and related products for relational data base management and SPSS for statistics and business graphics.

All data was translated from internal digital files to Intergraph SOF files and delivered on magnetic tape. Data checkplots were also supplied. The entire 500 square mile project was completed in just 10 months, all original costs and schedules were met and not a single data error has been reported.

Over the next few years, Orange County will be mapping additional layers.

Case Study #2

Pilot Project for Parcel Map Conversion Prince William County, Pennsylvania

This project required the conversion of newly recompiled parcel maps and delivery in ARC/INFO Export format. The source re-compiled maps were colored pencil on mylar maps.

The County had been manually converting their recompiled parcel maps. In an effort to speed up completion of the parcel database, the County requested a pilot study be conducted to determine the best method for automation. This pilot project consisted of four 1:2 400 scale parcel maps. Three of the maps required that a polygon coverage be created from all parcel lines. The fourth map was provided with a polygon coverage of all parcels and with all text on the map. The data was converted to the Virginia Coordinate System using 1983 international feet coordinates.

The coverages were clipped to a box having the four tics as corners. All four maps were edge matched to assure continuous data across map sheet borders. The digital data was supplied to Prince William County in ARC/INFO Export format on nine track magnetic tapes.

Case Study #3

FEMA Mapping Southwest Florida Water Management District

This project is significant because it involves the creation of a database by combining data from several sources, because it is being delivered to the client in ARC/INFO Export format, and because control information for the FEMA maps is being derived from a third source.

A 9 500 square mile, 15 county area in southwest Florida is covered by this project, making it one of the largest and most complex conversion projects of its kind. The maps to convert are 807 FEMA FIRM and Floodway maps, at scales of 1:12 000, 1:144 000 and 1:288 000.

The flood zones, hazard zones, political areas, river mile markers and reference marks, and hydrography are the layers, or coverages, captured. Thirty-four unique attributes are assigned to the five coverages. The coding scheme for the project includes a polygon, line, link and network coverage. This allows for maximum flexibility for spatial analysis.

Since the FEMA maps do not contain control information, a third source for control is necessary for conversion. Thus, all FEMA maps are reviewed with corresponding USGS quads for location of coincident features. Section corners, street intersections and hydrologic features are being used to determine control. The digitized linework is being transformed into Universal Transverse Mercator meter coordinates using control information derived from USGS quadrangles.

There are four key conversion difficulties associated with this project:

- The maps are not simply black & white. They are composed of a number of shades of grey, which are used to delineate different flood zone information, such as 100 and 500 year flood zones.

- The data is derived from two separate maps. The FIRM maps contain flood zone information, and the information from the corresponding floodway maps must be precisely tied to these maps to form the resultant polygon data set.
- None of these maps have horizontal control information. This control must be derived from the corresponding 1:24 000 scale USGS quad sheets.
- The firm and floodway maps range in scale from 1:6 000 to 1:24 000, and the floodway maps do not usually exactly correspond to a portion of a quad sheet. This means that up to four USGS quad maps may be required to develop horizontal control for a single floodway map.

Ultimately, all of these maps must be precisely edge-matched to form continuous information and then cut into USGS 7.5 minute quad sheet-equivalent tiles for use on the District's ARC/INFO system. In addition, the data from the FIRM and floodway maps are being combined. All the quadrangle maps are being edge matched to produce a seamless, topologically correct coverage.

The final data files are being converted to ARC/INFO files. The data is then generated to create line and point coordinate files, and built and appended to combine adjacent coverages. Finally, new coverages are formed in increments of USGS quad boundaries using CLIP. All data will be delivered to the District in ARC/INFO Export format by January 1990, which represents a six month completion time.

By February 1990, the Water Management District will have the data required for the FEMA layer of data needed for the GIS, and FEMA will have digitized maps that it can easily update and, in the future, to which it can tie street names and other pertinent information. This means that banks and insurance companies will have better data on which to base mortgage decisions and insurance rates, and city planners will have accurate flood and water management information at hand when issuing building permits and establishing building codes.

Case Study #4

Automated Conversion of Topographic Maps for District GIS Applications

Southwest Florida Water Management District

This project is significant because of the nature of the source documents: aerial photo contour maps. The map sheets contained 2-foot contours and spot elevations displayed on top of full grey scale aerial photography. This type of original is typically considered impossible to convert via automated processes. However, because of the use of unique grey level scanning capabilities,it was possible to apply the benefits of automated data capture to this project.

Contours were digitized from mylar separates of 1:1 000 USGS contours. All 2-foot contours, spot elevations and associated Z values were captured to an accuracy of 0.004". The plots also exhibited the scale of the plot and maximum and minimum real world values computed for the data captured. The data was converted to UTM coordinates and delivered in the USGS DLG3 optional format on 9 track tape at a density of 6250 bpi for use on an ARC/INFO system. In addition, a final check plot on 4 mil double matte finish film was provided for each sheet.

This project covered an area of approximately 600 square miles and was completed without a single digitizing error being reported.

Case Study #5

Production of Digital Cartographic Base Maps from USGS Quadrangles

This project involved the automated conversion of USGS 7.5 minute, 1:24 000 scale quadrangles for use in the ITT Rayonier, Inc. Southeast Forest Resources PC ARC/INFO system, The database covered approximately 100 000 acres of ITT Rayonier property in five Georgia counties.

Five data coverages were created from the quadrangles: transportation, hydrography, political, point, and section coverages. Within these five coverages, forty-three unique features were identified:

Transportation

Four lane or divided highway

Primary highway, hard surface

Secondary highway, hard surface

Light-duty road, hard or improved

Unimproved road

Jeep trail

Railroad

Abandoned railroad

Tram road

Airport

Powerline

Telephone line

Pipeline

Map neatlines

Hydrography

Intermittent drainage
Rivers

Perennial drainage

Map neatline

Ponds, lakes,
reservoirs

Bays, oceans

Political

State line

County line

City boundary

Point

Church

School

Boat ramp

Forest Ranger station

Police station

Radio tower

Towns, villages

Benchmark elevations

Gates

Cemetery

Hospital

Lookout tower

Fire station

Section

Township or range line

Section line

The digital database was created via an automated conversion process. All graphics, polygons and attributes were formed there. All data was converted to Universal Mercator coordinates. Each map sheet was coordinate edge matched, within each respective layer, with adjacent map sheets to provide a contiguous database.

This data was then translated into ARC/INFO format. All coverages were cleaned and built. Two copies of the quad sheets were delivered to ITT Rayonier. Each quadrangle was delivered as an individual 7.5 minute map, as well as edgematched and appended to form coverages per ITT Rayonier specifications. The data was delivered in PC ARC/INFO format on high density 5.25" floppy diskettes.

The 21 quads were delivered in 60 days.

Case Study #6

Automated Conversion of Soils Maps For the USDA - Forest Service, Olympic National Forest

This project required the conversion of approximately 10 000 soils information polygons with associated attributes from 91 map sheets at a scale of 1:24 000. The resulting data files contain the soil polygons with the major soil, minor soil and slope associated with them.

To produce 91 digital map files of soils information polygons in MOSS format, six crucial functions took place:

- lines were captured to a specified degree of accuracy;
- the linework was edited;
- polygons were attributed with soils information;
- the attribution was edited; and,
- MOSS files were written to an unlabeled tape.

A very brief process description follows, describing how each of the above functions was addressed.

After project setup, each mylar was scanned at 100 pixels per inch, which provides an accuracy to within 0.01 inches. An automatic raster to vector process identified virtually all linework and polygon intersections on the maps and, by appropriately setting parameters, was able to ignore the annotation. A file of unattributed line segments was produced.

At the interactive edit workstation, the operator reviewed all linework by viewing the digitized vectors on the screen with the scanned image in the background. Line segments and intersections were easily added or modified. The editor then formed polygons from the line segments by merely selecting the desired segments of the polygon. After all polygons were so determined, the system looped through each polygon, prompting the editor to enter the soils information attribute, which was read by the operator from the background image. The polygon formation was assured by the operator during this process, and the typed attributes, in the proper three component/slash format, appeared on the screen for easy checking.

The registration tics and their values were then entered at the workstation. The polygon endpoints on the edges of adjacent maps were represented on the screen relative to the current map. Each endpoint was matched with an endpoint from the current map based on location and matching attributes, and this was indicated visually on the screen. Any unmatched endpoints were easily identified and resolved. At the end of interactive editing, the digitized data for the map consisted of clean, accurate linework in a polygonal structure, attributed, and with pre-reviewed edge matches to adjacent maps. All data had been edited and coordinates were in an internal system.

A batch process then converted the internal coordinates to Washington Zone 4601 state plane coordinates. Another batch process performed the actual edge matching of the endpoints on adjacent maps. Plots and listings were produced for the second stage of quality assurance. This second stage re-verified that the plotted data overlaid the original maps, that polygons were properly formed with correctly entered soils information, and that the data on adjacent maps all merged correctly. Any errors were rectified at the interactive edit workstation.

After each map was verified as correct, all data was converted to MOSS EXPORT format files. The MOSS files were written to an unlabeled tape, at 1600 BPI, in ASCII with a blocking factor of 8192. The final product was a continuous real world soils database for the entire Olympic National Forest, approximately 2 800 square miles.

Case Study #7

Automated Conversion of 1 100 USGS Quads for use on a Corporate GIS

This project, completed for a major U.S. oil corporation, required the conversion of approximately 1 100 7.5 minute and 15 minute USGS quadrangles. Four major layers of information were captured from the quadrangles: hydrography, transportation, boundaries and points. Nineteen unique features were identified within these layers. The resulting data was fully topologically structured, converted to latitude and longitude coordinates and edgematched, regardless of the scale of the source maps. The result was an absolutely continuous real world database covering approximately 80 000 square miles.

The data was structured per USGS DLG standard and delivered in a client-specific format.

Approximately 1 100 digital files on 9-track tape, as well as final checkplots, were delivered in approximately ten months, and fewer than 0.5% of the maps were found to contain even a single error. The original schedule called for the completion of 1020 maps in nine months. This goal was met. An additional 50 quadrangles were added during the final months of the project, and an additional month was added to the delivery date. The cost of the project remained as budgeted.

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Fast Track to Database Completion

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Abstract

BC Hydro started its AM/FM system in 1983. Conversion began in-house with land data translated from two existing AM systems. In 1987, the system was extended to all four operating divisions and April 1989 saw establishment of a major project to contract conversion of the remaining distribution system by March 1992. Approximately 10% of this work will remain in-house.

Conversion contractors have established permanent operations in two interior BC cities and will complete the conversion of land and electric facilities data for an electric utility with more than 1.2 million customers and a total service area of 72 800 square kilometres. In-house personnel had converted 18% of the land base, plus 10% of the electric facilities and are continuing to convert about 10% of the remaining area.

In addition to the fast track conversion schedule, more than $6 million will be spent on applications development by March 1992. This presentation will review this ambitious project and the efforts to establish a lasting data conversion industry in British Columbia.

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Current and Future GIS Applications in the City of Halifax

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Abstract

Geographic information system implementation within a municipal environment varies from one city to the next. History, politics, and staff all play a major aspect in its successful implementation. This paper will highlight the events that has brought Halifax into the world of Geographic Information Systems.

Introduction

The City of Halifax became a full fledged user of geographic information systems in 1986 by engaging a service bureau to digitize our sewer and water utility information. During the fifteen years before the signing of this contract, the City of Halifax went through many changes in its actual size and shape and in its outlook on information management. These changes were to be the building blocks upon which our GIS would be structured.

Until 1970, the City of Halifax comprised only the peninsula and did not include several small 'mainland' communities. With the annexation however, the City nearly doubled its size and was faced with combining two sets of base maps: 1:480 for the peninsula and 1:1200 for the mainland.

To co-ordinate activities, members of the Nova Scotia Power Corporation, Maritime Telephone and Telegraph Company, the Halifax Water Commission and the Engineering Department of the City of Halifax formed the Halifax Utility Co-Ordinating Committee (HUCC) in the mid 70's. After the Committee's investigation of the feasibility of integrated utility mapping, they were unanimous in the need for the creation of new topographic base maps as the first step.

At that time, Land Registration and Information Services (LRIS), a provincial agency responsible for mapping, had as its priority resource mapping and not urban mapping. As a result, the HUC Committee explored avenues for creating its own urban mapping. In 1980, their report, 'Feasibility of an Improved Mapping System', revealed that at 2.5 million (1980) dollars, they could develop a new digital topographical database and necessary utility programs.

The venture was felt to be too costly to receive a firm commitment from the senior management of the Committee members and the efforts came to a standstill.

However, in 1981, LRIS decided to switch its emphasis back to urban mapping. They did the aerial photography for both Halifax and Dartmouth, and began a digitizing program for the topographic base which was completed in 1985. The City, anticipating its future need for digital mapping, approached LRIS to digitize sidewalk information and, although it is not standard for 1:1000 mapping, they complied.

While every city has some form of base maps, it is important to explain the extent of detail that makes up our topographic base. This detail includes pavement edge, buildings, 5 meter contours/spot heights, landcover (shrubs, trees, etc.), structures such as guard rails, billboards, fences, etc., designated areas (parking lots, playgrounds, parks, etc.), hydrographic features, driveways, lanes, walkways and sidewalks.

In 1986, with the new digital topographic base maps available, the City signed its first geographic information systems contract with the Eastcan Group to convert our hard copy sewer and water records. This contract included the:

- development of symbology;
- feature coding;
- data capture;
- topology;
- hardware and software;
- online access; and,
- human resources.

This project included many man-hours on the part of City employees to prepare the necessary data through its various phases. The team of City employees 'scrubbed' the source maps and collected attribute data. The process evolved into these main steps:

- all features were plotted on original maps using existing in-house information;
- clear acetate overlays were used to label each feature;
- for each feature, a data attribute record was prepared;
- attribute data was keyed into an in-house database and transferred electronically;
- graphic source documents were sent for digitizing; and,
- after digitizing, check plots were produced for verification.

This process revealed that the quality of the City's data was not quite up to the level we had always believed. As with any project, many aspects would be done differently if it was to be done over, and the lessons learned will be used in the next conversion projects.

The next significant event that proved the City of Halifax was moving into an enterprise-wide geographic information system was that the City's Planning Department entered into an agreement in early 1987 with LRIS to develop a digital parcel database. At this point, we now were positioning the City of Halifax to have the three fundamental databases needed by any municipal government: the topographic, sewer and water utility, and parcel databases.

On the heels of this contract signing, the City did a complete assessment of its computing requirements to take us into the 1990's, with the assistance of Robert Liley and Associates Consulting. In late 1987, City Council adopted the Systems Implementation Strategy. The strategy included the following recommendations:

- the acquisition of new computer facilities capable of expanding as needs increase, and a communications network;
- new software development tools;
- protection of the current investment in micro computers;
- single workstation access to information; and,
- implementation of in-house geographic information systems

It is very important to understand that this strategy was driven by enterprise-wide effort, as all major departments participated in its development.

It is also important to note that each of these recommendations were to be implemented by various task forces also made up of major user department representatives. As a result, in 1988, the Geographic Information Systems Task Force was created with representatives from Engineering, Finance, Development and Planning, Works, Public Safety and Management Information Services.

Number one on the GIS Task Force agenda was to define the functional requirements needed by the City in choosing its GIS software. In the examination of these functional requirements, the task force put forward the following recommendations:

- utilize a service bureau as necessary;
- initiate on-going GIS database maintenance;
- acquire the appropriate GIS system software;
- acquire specific hardware subsequent to software selection;
- acquire/develop GIS related applications;
- integrate business systems with GIS;
- develop and implement policies and procedures; and
- update human resources requirements.

Throughout this phase, we enlisted the services of Karel Fila, GIS Consultant, to assist City staff in learning and understanding the issues associated with the implementation of GIS.

The next phase of actual GIS system software selection required the City to create a benchtest of all the functional requirements we felt necessary for our operations. Again, we enlisted the services of Karel Fila to help create, execute, and evaluate the benchtest results and subsequent contract negotiations.

In August of 1989, City Council approved the contract with ESRI Canada which included GIS system software (ARC/INFO), hardware (SUN), data conversion (NTX to ARC), installation acceptance and a performance guarantee.

The other recommendations were also worked on concurrently. The first GIS staff position was filled, the updating of 15 topographic map sheets commenced, draft policies were developed and a sewer database maintenance report was created. Also, the task of data conversion began. A small section of the databases was extracted to be used as a pilot area for the conversion process. After several detailed verifications and modification to the conversion test, the City was ready to design the database layout for our system. The ARC/INFO system uses a file organization called 'TILES'. It was mandatory that the City first weigh how many TILES were necessary to create the optimum response time against the effort required to update these TILES.

We determined that four (4) tile schemes, municipal parcel utility, and NS 1:1000 would be appropriate for our needs.

The municipal tile (1) contains street centre lines, control monuments, municipal boundaries, water details and administrative coverage, e.g., zoning, wards, polling districts and police zoning.

The parcel tile (12) contains parcels, buildings, civic numbers, trees and miscellaneous features. The utility tile (25) contains curbs, sewer, water and utility coverage. The NS 1:1000 tiles (193) contains contours, spot heights, land cover, sidewalks, driveways and hydrography.

With the database (tile) design complete, ESRI commenced the full conversion process. At the same time, the GIS system software and hardware (SUN) were installed at our offices and City staff began training in ARC/INFO.

The converted data was loaded on this new system and we then started the installation acceptance process. Problems that surfaced along the way were quickly rectified by ESRI and we were able to begin the performance test. This exercise was to test the new GIS system software running on our hardware within our full database, simulating an expected normal day of operation for 20 users.

This proved to be a stimulating experience for both City staff and ESRI, and after certain hardware and software adjustments, the City accepted the system.

Other activities that have been going on include the hiring of a GIS Co-Ordinator and a GIS programmer, policy statement review, the development of standards, and investigation of potential applications. These activities have all been directed by the GIS Task Force.

For a department that so recently came into existence, our services are increasingly in demand.

The City has been working on CORE database (parcel and sewer) maintenance procedures which are planned to be implemented by late spring 1991. We will continue to enhance the general query system as there are currently 17 query users covering all major departments using the GIS data on a daily basis, with 15 more to be installed by the end of February 1991.

The City has also been working with the Halifax Harbour Cleanup Corporation (HHCC) and its consultants to provide an effective information exchange. We became part of their digitizing pilot test. Once provided with their files, we loaded them on our system and combined them with our sewer and water data.

The City is also starting the development of a track of land known as the Mainland Commons. The Mainland Commons Committee have made it mandatory that the consultant firm provide conceptual and detailed plans in an electronic form compatible with our GIS system software.

We are currently determining the electronic specifications required for all information being supplied. Record drawings and development proposals will be presented in digital form and will have a determined level of accuracy associated with them.

1991 promises to be another interesting and busy year. Several new projects are in the immediate horizon, as well as the ongoing and indeed never-ending one. Halifax, with the capabilities of our GIS system, will be striving to increase the quality of its service to the taxpayers.

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GIS and the Smaller Community

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Abstract

Robert Liley and Associates has worked with local governments across Canada and internationally in planning and implementing geographic information system concepts to support government operations and decision making. While the basic elements of planning for GIS remain the same regardless of the size of the community, the issues surrounding and arising from the implementation of GIS in smaller centres have much different implications. In smaller centres, it is usually much easier to form a cross-functional task force which can see the GIS opportunities for the community as a whole, 'turf wars' are much less of a problem. But, while the costs of GIS hardware and software have dropped dramatically, making GIS 'affordable', the overall costs of GIS implementation remains formidable; and these costs represent a major portion of planned expenditures. Moreover, much of the outlay is required years before any major benefits can be derived. This necessitates an investment decision on the part of council, something with which councils don't often deal. And simply extending the implementation period to defer the costs unfortunately defers the benefits as well.

Because of the visibility of GIS projects and the associated uncertainties, the risks of failure are high. No solution is available off the shelf. Scarce resources must be committed to the undertaking for substantial periods of time. Lastly, council and management expectations may not always coincide with the practical realities of implementation. This paper discusses some of our experiences in assisting smaller communities to implement GIS capabilities.

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The Corporation of the Township of Richmond: URISA Exemplary System in Government Awards

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Abstract

Richmond's Property Management System consists of two distinct components. One is the digitally stored map data overlays and the other is the traditional business systems. The Geographic data management system (GDMS) is an application 'bridge' between the two components. Richmond has created multiple map overlays and business systems to create a complete system. Richmond staff can easily retrieve information from either component. A property-tax assessment inquiry can link into the zoning, agricultural land reserve or drainage levy area map overlays and display this information. This allows computerized map inquiries without physically perusing multiple maps. Some data such as zones or permit areas should be updated graphically on the map data. Zoning changes can affect multiple properties. Therefore, digital changes rather than business system updates will save time and effort. With the mixing of graphic and business data, Richmond can answer public and internal questions very simply with its Property Management System.

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GIS Integration With Business Systems

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Abstract

Pre-implementation of a GIS all too often concentrates solely on the mapping characteristics with little thought being given to the maintenance of the data behind these map elements. The concentration is directed at defining the GIS data base and the representation of the data on the maps to be produced. The cost of a GIS will not be recovered by just producing maps. The real power of a GIS, and the large payback, will come from the new capabilities to analyze business operations spatially and then representing them in all three modes, spatially, textually and graphically. Therefore, the success of any GIS will rely heavily upon the ability of the business systems to integrate with the GIS such that the business data can be used in the analyses. Further to that, much of the attribute data related to the data elements within the GIS really needs to be maintained by the regular course of business versus the time consuming manual updating on a workstation of every data element which has undergone change. We do not have the personnel to keep a GIS current under these manual methods. Our thoughts must turn to the automatic maintenance of the data, in a timely manner, in order to secure a GIS which represents the current status of the municipal operations. Integration of the business programs with the GIS DBMS is the only practical and economical solution.

Introduction

The fever attributed to the implementation of a GIS is spreading through municipal management at all levels. The interest usually appears first in the Engineering department of the municipality, as that group has wrestled with the production and maintenance of maps for numerous ye[illegible]ow. Over the last decade, GIS has grown from AM/FM programs so a major focus of the vendors has been on the mapping abilities of the products. The headaches attributed to the lack of adequate maps reached a point where map automation supplied the justification to acquire the software by the larger municipalities. Time and advancing technology has made this route more palatable to many more municipalities. In fact, any municipality having a population of 35 000 is quite able to afford some degree of automated mapping. Note that I have not said a GIS. However, once the second topic of facilities management is raised, the cost of the system increases dramatically. Even getting map conversion at the scale needed to manage the municipality's infrastructure can be too costly for any but the most financially well off municipalities.

Realizing that mapping alone is not a sufficient justification to warrant the expense in equipment and personnel for automating the reproduction of maps, a broader utilization is required. Granted the computerization of maps will allow many permutations of the layers of data elements to generate selected maps at will. But, even so, the savings attributed to draftspersons is not sufficient to establish a marketing case to management. Any mapping savings or enhancements compared to the full tally of costs does not impress management nor the public officials who are concerned about large allocations out of the public purse.

Broader utilization can often extend only to that of facilities management before justification of the expence is warranted. Often, the municipality realises that such an investment can benefit more, if not all, departments or agencies at much less incremental effort. Now, a GIS can become a reality within the organization if more departments perceive benefit and thereby join the Engineering department in its campaign for a GIS, and the allocation of funds to implement it. However, the real interests of these other departments deviates significantly from the accuracy and depiction of Engineering-related elements to that of polygonal and socio-economic analyses. The dichotomy is now struck: how to please everyone under the guise of a single system implementation?

What Is a GIS?

In some ways it can be easier to describe what a GIS is not. It is not:

- a packaged system implementable upon purchase;
- solely a mapping, an analytical or a graphics program;
- a finite system which can be considered implemented at a point in time; nor
- a panacea system addressing the remaining problems of municipal management.

A GIS must be considered as another 'onion skin' system in much the same way as an MIS (Management Information System) has been described, and often redefined over the last decade, for the unification of business systems in order to obtain inter-related management insights and the exploration of possible actions. So too, the GIS is an 'outer layer' concept that shares the same 'skin' level as the MIS and should be thought of as merging with the MIS concept in its implementation. Any attempt at implementing a GIS without serious consideration regarding integration with the business systems will be a tragic failure for the organization, which will severely restrict the opportunity and limit the financial benefits by at least an order of magnitude.

Just as many people have had trouble in defining exactly what an MIS is, so too, the universal definition of a GIS meets with equivalent numbers of voices of support and disagreement. The truth is that a GIS will assume the character of the organization installing and developing it to suit its own management style. The essence of the GIS will be founded upon the business operations of the municipality and the management methods employed. Knowing that business systems in a municipality undergo constant additions and changes over the long term, it can be assumed, just as easily, that the GIS will be equally dynamic as operating criteria dictate. It must be realised by all participants that "*...the implementation of a GIS is a Journey ... not a Destination*".

Oversights When Selling the GIS to the Organizaiton

In the attempts to appeal to the greatest number of department heads in the municipality, and sometimes to similarly interested agencies working with the municipality, the establishing of a pilot project to demonstrate the viability of a GIS usually materializes. This is 'sold' with the notion of identifying sources and uses of the data and also to expose the numerous methods of managing the data through the display of information in both graphical and spatial formats in a cost limited basis through selection of a 'representative' area of the municipality. This pilot also has the deliverable of identifying costs of implementation. Unfortunately, there is seldom an all-encompassing region of representation for all parties interested, so some latitude in the development of the pilot is introduced. But the greatest oversight now occurs, that of cost containment and a disposable mind set to the project which precludes the costly and time consuming effort of converting business systems to interact with the GIS pilot program. If the business systems were to be acquired or rewritten to link to the GIS, then the work would have been done and a pilot project is moot. The effort and time to do this are recognized to be excessive and so for the pilot project, data is manually loaded. Because of the lack of automated business updating, the only maintenance of the data is through manual interaction. The realization and comprehension of integrating business systems with the GIS is lost. Observers are lead to believe that the GIS is a stand-alone system which can exist outside of the automated business functions.

The zoom out of, and telescoping into, the pilot project map area to display overviews and details of the loaded data causes much excitement in the eyes of the on-lookers. Unfortunately, like seeing a fantastic new tool displayed at the county fair, the crowd is mesmerised by the slick operation without comprehending the requirements behind the scene. In the case of the GIS pilot, the data is usually several months out of date, but, the question is seldom ever asked as to how it will be kept current upon implementation. If it is asked, the specifics are usually glossed over by a statement to the effect that "The staff will maintain it in their normal course of work". The inquirer is satisfied and moves on to other points of interest. If you reflect upon the overload of work before municipal staff right now, where is all that time going to come from to maintain the integrity of the GIS data base? A simple calculation performed by multiplying the time it took to load the pilot project's data base by the total area of the municipality, of which it represented a small fraction, will open many eyes to the real magnitude of the effort. Add to that another twenty percent, due to the fact that the pilot project area is usually far less complicated than a good part of the remaining municipality. Municipalities have identified some 2 300 to 3 000 data elements to be used to depict features on the maps of which approximately one-half are identified at pilot operation. Compound that with the realization that a considerable percentage of the municipality's data is changing, in some way, on a daily basis and must be updated in a timely manner after implementation. You just do not have the personnel to keep up with it, and most Councils are not going to approve the huge hiring of additional personnel required to accomplish it. So, what is the solution?

Integration of MIS and GIS

Integration of the MIS and the GIS accomplishes two major aims: it supports multiple data base integrity and it is the practical method of keeping data current. The only way to attain integrity of the data stored by the municipality in both the MIS and the GIS is not to have redundancy in separate databases. Without this singularity of storage, it is too easy for editing of one form or another to cause data items to become out of synchronization. This implies a requirement to 'view' the data in each DBMS through either system. This is the first level of integration, data sharing.

The ability to inquire through either a spatial selection, such as an encirclement of elements on a map display or through a selective command using delimiting criteria, such as SQL statements, should be readily available to users of the Municipal Information System. We now have the next level of integration, data linking. There must be an inter-database capability for the linking of elements such that selection and display can be done through either approach. The data value or placement of discrete elements cannot be lost through traditional database parent-child structures and summaries, otherwise, the ability to delineate and display data inquiries and analyses will be severely restricted.

Daily business operations throughout the organization cause significant changes to the data relevant to the management of the municipality. Progress into a GIS for operations-support and decision-support capabilities which is thwarted by waiting for some designated updating session or job stream is a regression to 'batch mode' operation and re-introduces all the problems of non-source data capture and delayed time to actual reflection. We have come a long way towards achieving on-line and real-time data capture and representation in our business systems, so why forsake these principles when implementing a GIS?

Let the business systems maintain the dynamics of the data, to the extent possible. Of course, there will still be the necessity of graphics input regarding the map elements of symbols, points, lines, polygons and attribute data associated with each. However, that attribute data should be very limited, as much of what is called attribute data today in GISs, and especially pilot projects, can be obtained from the business records if integration is performed. By so restricting the attribute data, the manual maintenance of the geographical data elements is kept to a minimum, is more timely through routine automation, and is less likely to be falsified by casual editing.

If we are able to initiate an updating process in either the MIS or the GIS such that the ensuing operation is comprehensive, that is, data is changed where possible or permissible and related elements are flagged as requiring modification by stand-alone actions or a security requirement, then the integration of the GIS with the MIS has attained the highest level, that of operational sharing.

Where Do We Start Integration?

The implementation of any GIS is founded upon the base map. Usually this comprises the topographical map and the cadastre for municipalities. That implies that a Property Data Base is needed to record the cadastre details other than the geographic boundaries. For most municipalities, property records is a business function currently existing as the primary storage behind their taxation program. For others, where taxation is performed by another government body, there is usually just a Property Records System of not much more than a Property Roll Book list. Unfortunately, with the relational database developed software just now appearing in municipalities, it is likely that these programs are file-oriented which will require conversion into a relational data base for integration. In most cases, program changes will have to be made, or a new system acquired, in order to make appropriate use of the relational data storage architecture.

The chain of events is now set: determine the foundation data sets, obtain an entry and update program, and develop and acquire operational programs linking to it. This sequence will apply to all operations throughout the municipality. In some cases, the foundation data set overlaps that which has already been identified and so becomes a subset on the differences only. The edit and updating should, for the most part, be controlled through the applications developed. Here is a point of contention: who has the right to modify the data? These rights must be determined, collectively, identifying exclusivity for some items and a heirarchical protocol for less sensitive data items. The operational programs may have to be a collective development due to this editing permission on the data. It is unlikely that off-the-shelf programs are available which will address precisely your municipality's requirements for data sensitivity, security, validity and historical logging. Be prepared to do a considerable amount of in-house development in order to achieve the integration necessary for a truly beneficial MIS-GIS operations-support and decision-support system.

An analysis of needs and costs will be necessary to set priorities on applications implementation. In many cases, it will appear that movement must occur on a broad front. This will only be possible by adopting a strategy within the constraints of your resources and budget. In the early stages, the establishment of the foundation data sets requires a rather broad implementation plan. Following these primary databases, of which there are six major classifications for municipalities, applications can be implemented as per justification. Often, decisions will have to be made to sequence the implementation of new business systems in accordance with the implementation of the related or prerequisite GIS software and equipment.

Integration: Is It Really Worth the Effort?

The way we utilize data, in order to provide us with information such that we can perform our jobs better, is going to change dramatically. If we do not adhere to this direction, then we are conscripted to struggling with text and numeric reports to represent the eccentricities happening in our municipalities. Yes, we can depict the numbers using business graphics packages and even employ draftspersons to map our analysis, but this is the confining environment in which we now operate and we are saying that it is not effective. What other options are there within our cost constraints that are timely enough to make a difference?

To implement a GIS without the integration into the business applications can achieve much more than what we currently do, but is done so at that outmoded level of batch updating and with severely restricted information for analytical purposes. A fully encompassing GIS cannot be maintained in light of the workload added to the personnel. Therefore, anything within personnel capacities will be considerably less in terms of data available. The choice is to determine, in advance, what data will be insignificant in the management of the municipality over time; a very tough choice to make.

I maintain that the really significant uses of a GIS are yet to be discovered. The provision of the tools to the operating and management personnel will enable them to reveal unforeseen applications by their ingenuity. These applications of the GIS are unapparent to the systems builders as they deal with the product from a different perspective and usually without the on the job exposure to operational and management problems. As most great discoveries in science occurred through serendipity, I believe that the great advances in municipal management will only occur through the MIS-GIS integration which creates the environment for progressive investigation and serendipitous revelation in this arena.

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A Regional Information Centre - A Planning Supermarket

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Abstract

This paper discusses the electronic information library maintained by the Development Services Department of the Greater Vancouver Regional District. Their experience may be a useful model for other groups considering offering a similar service. The paper outlines the range of information services available, indentifies client groups and examines some benefits and costs of the service. The data centre service has been available internally for ten years and to external clients for more than five years. The services include access to transportation modelling, a geographic information system, and a cohort survival population forecasting model. The information service is provided to internal clients, member municipalities of the District and other public agencies free of direct charges. The service provides access to information that is particularly relevant for the work of economic development officers, planners and transportation specialists. Private sector clients, such as commercial real estate developers, find the concept of one stop information shopping particularly attractive. In addition to the data resources, the knowledge and expertise of the staff members is a particularly valuable component of the service.

Introduction

A Regional Information Centre - A Planning Information Supermarket

The Greater Vancouver Regional District is an agency whose function is to provide services to member communities of the region. These services include water system supply and management, sewage and drainage collection and treatment facilities and administration of provincial pollution control regulations. The development of a regional information centre was an almost natural extension to the District's range of services to the municipalities of Greater Vancouver.

In the late 1970's, the Planning Department of the Greater Vancouver Regional District was empowered by provincial legislation to provide planning and development policies to achieve orderly and sustainable patterns of growth throughout the region. These policies and guidelines formed the basis for an Official Regional Plan. To develop the plan, monitor the effect of the existing policies and to explore impacts associated with policy changes in the Official Regional Plan, there was a need for information gathering, maintenance and analysis tools. Much of the information relevant to these issues was geographically based. As a result, a Land Use Information System (LUIS) was developed. The primary information resource for this system was patterns of land use throughout the region. Over time the base system evolved to encompass socioeconomic information derived from the Census of Canada as well as information related to Commercial and Industrial developments. As the information base grew, the use of the system expanded from the original core in the planning department, to other departments of the Greater Vancouver Regional District and to planners in municipalities throughout the region.

As a result of legislative changes in 1983, the regulatory planning function was removed from the mandate of the regional district and the Planning Department was disbanded. However, the information needs of municipal planners for a regional repository of planning related information remained. The planning department data resources and information systems were transferred to the Development Services department. This department was structured to provide municipal planning and engineering departments with access to a variety of information related to regional and local social, economic, demographic and transportation issues.

Shortly after the formation of the Development Services department, transportation modelling software (EMME/2) was acquired as an additional information processing and analysis tool of the department. Since late 1984, access to the regional transportation model has been available to all municipalities free of charge. The transportation model and related information is maintained and supported by Development Services, with the assistance of a steering committee comprised of representatives from municipal planning and engineering departments, British Columbia Ministry of Transportation and Highways, and BC Transit.

The same intermunicipal and interagency cooperative structure has developed for geographically based social, economic and demographic information. The information maintained for this portion of the departments work program consists of Cohort Survival Population Forecasting Model, General Monitoring Information and Spatial or Geographic Information Systems.

The four systems support a wide variety of internal and external users of the information resources. In subsequent sections, this paper will discuss each of these systems, including the general information components and the associated client communities.

Technology Environment

Before discussing the information resources, a brief overview of the computing and communications resources of the Greater Vancouver Regional District is necessary. To support internal applications and information service clients, the regional district operates five Digital Equipment VAX computers running the VMS operating system. Three of the computers are clustered with the other two machines connected via Digital's network communications software DECNET. The external clients of the system establish sessions, under their own usernames and passwords, on the computer network through dedicated lines or dialup 1200/2400 baud modems. All of the permitted information resources and services of the regional district are available to our clients through a single session established on the computer network. To reduce requests for technical assistance the District requires that potential clients use one of three approved terminal emulation software packages.

Although access to the data resources is free to member municipalities of the district, private sector firms and other agencies are charged for use of the systems on the basis of connect and processing time as well as disk storage.

1. Transportation

The EMME/2 model is used by regional or municipal traffic planners and engineers for the analysis of transportation infrastructure changes as well as for estimating the impact of local commercial development and the effects of general population growth within municipalities or throughout the region. Since the model is regional in scope, the impact of local transportation network changes or improvements may be analyzed both within the responsible municipality and in any adjoining communities.

The transportation information resources available to clients include:

- A regional transportation network for Greater Vancouver and the Lower Fraser Valley based on a 380 zone system, comprising approximately 7,000 links, 2,300 nodes and 160 bus routes. The network includes all major streets, bus and transit routes, and intersections with turn restrictions.
- Census of Canada data for 1971, 1976, 1981 and 1986 such as employment by industrial and occupational groups by place of residence, employment by place of work, labour force activity by age and sex, level of educational attainment, school attendance and income level by age and sex.
- GVRD proprietary information derived from an origin - destination travel survey conducted in 1985.
- Traffic zone forecasts of population, labour force and employment and trip assignment tables for the period 1991 to 2011.
- Traffic volume counts for major streets and intersections within the Greater Vancouver area and the Lower Fraser Valley. This information is derived from a number of sources including British Columbia Ministry of Transportation and Highways, municipal traffic count programs and from GVRD commissioned traffic count studies. All traffic count data has been standardized in format and adjusted to compensate for seasonal variations. Additional information is available to classify the traffic counts by vehicle type and occupancy levels.

All of this information is available in its original form as well as in the form of origin - destination matrices or trip tables within the EMME/2 system.

The regional transportation modelling system (EMME/2) has been available to clients since 1984. Currently, five high volume clients are using dedicated connections, an additional 12 to 15 clients establish sessions over dialup lines. Transportation modelling is not an activity that is undertaken without considerable training and experience; as a result, the District has expended significant efforts in developing and delivering training courses and demonstration materials to this group of users.

2. Spatial Information

The spatial information maintained by the District falls into three major categories: Census of Canada, Land Use and Commercial / Industrial Floorspace. Most census data is available in an aggregated form at the level of census tract or enumeration area polygons, but some information such as raw block face counts of population and households is maintained as point data with specific geographic locations. The Census data is available for 1971, 1976, 1981 and 1986. The Census data includes several hundred variables, with the majority relating to the 1986 Census. Land use data is available for the years 1976 to 1983. The land use information is only available as polygon aggregates. Some internally generated information such as population, household, labour force and employment forecasts are available at the level of traffic zones.

The Commercial / Industrial Floorspace information is maintained on the basis of individual properties throughout the region. Commercial / industrial floorspace information is available on a parcel basis for 1987 and 1989 with data for other periods maintained in summaries by municipality. There are two information types within the commercial / industrial floorspace application: completed buildings and buildings under construction or proposed. All records in this application are geocoded using the exact address with coordinates assigned using the Statistics Canada Area Master File.

To facilitate retrieval of this geographically based information, digitized polygons are maintained for 1971, 1976, 1981 and 1986 enumeration areas and 1981 and 1986 census tracts. Additional map layers for traffic zones, municipal boundaries, regional town centres and other commonly requested geographic aggregations are available.

Spatial information retrieval and analysis is managed with the LandTrak Geographic Information System. Commonly requested information such as commercial / industrial floorspace, population counts and household characteristics or age specific profiles are maintained as prebuilt applications. All other polygon based information is stored as normal files on the computer system with automated routines available to generate custom applications and data sets. In some cases, users of the spatial information services may import their own information to the geographic information system for display, reports or thematic maps. After defining a data set appropriate to their requirements, users of the system are able generate any customized map layers or data aggregations for their analysis. Reports can be generated in tabular format or as export files for transfer to spreadsheets or graphics packages. In addition, thematic maps can be created and printed on an inkjet printer or 8 pen plotter up to D size.

This application serves the most varied group of clients. They include internal users such as water and sewer system planners, air quality monitoring staff, hospital planners and housing analysts. The municipal client base includes planners, transportation engineers, social services, parks and recreation, and school board staff. External clients include real estate developers, students, businesses, churches, crown corporations, charitable agencies and members of the public.

3. General Monitoring Information

The General Monitoring Information System is used primarily to maintain non-spatial time series data. The information resources consist mainly of indicators of the regions economic activity. The data sets available are quite extensive and include:

- monthly housing starts by type and municipality;
- value of building permits issued by municipality;
- labour force information including employment, employable population, unemployment rates and labour force participation rates;
- family allowance and old age security transfers;
- annual births and deaths by single years of age;
- consumer price indices;
- average weekly earnings; and,
- retail sales by type of store.

The data management system used to maintain this information consists of routines to create, update and report as well as to graphically display user specified data sets or tables. Most of the information is manually entered as it is released by the collecting agency. The system provides facilities for importing information from data files or exporting complete tables to spreadsheets for further analysis.

The information is most widely used within the Greater Vancouver Regional District for regular publications such as Economic Monitoring Bulletins, reports to internal committees and other agencies. However, since much of the information contained in this component of the data service does not exist in a similar form anywhere else, there is a substantial external demand for the publications based on the information and for the original data.

4. Forecasting

The Cohort Survival Forecasting Model (COHORT) is used to produce regional and subregional forecasts of population, housing demand and labour force by single years of age and sex. Several alternative demographic forecast series are maintained, these usually involve differing assumptions for the level of net migration to the region.

The information base for forecasting consists of population by single years of age 1971, 1976, 1981 and 1986, age and sex specific mortality rates, age specific fertility rates, and net migration propensities by age and sex. For housing demand forecasts, historical data on dwelling type household formation rates by age and sex are maintained. Labour force forecasts are derived from the population forecasts by applying age and sex specific labour force participation rates. The regional forecasts of population, housing demand and labour force are disaggregated to municipalities as well as census tracts or traffic zones for detailed analysis within the transportation model or geographic information system. As is the case with the other systems previously described, all of the forecasting information generated or maintained may be made available to any of the member municipalities or clients of the Greater Vancouver Regional District information systems.

Production of the forecasts involves considerable interaction between the District, member municipalities and professional forecasters. The regional base population forecast is developed in consultation with planners and forecasters working for other government agencies, to identify and assess trends for the base assumptions. When the municipal forecasts are prepared, extensive reviews are conducted with planners to determine the growth potential and capabilities of areas within each municipality to allocate the regional growth shares appropriately. As a result of the close working relationship of all the participants in vetting the forecasts, there is wide acceptance of the final results.

The forecasts of population, households, labour force and employment are widely used by Regional District departments for long range water and sewer system planning as well as by municipalities and private or public sector firms. The centralized approach to demographic forecasting has proven to be very effective in merging the diverse development aspirations of the region's communities.

Conclusions

After almost ten years experience in operating a centralized information service, the benefits and costs of the service are readily apparent. The most significant benefit derived from the service is the degree of cooperation and interdependence that has developed between the Regional District and the member municipalities of the region.

Some of the most obvious benefits accrue from the standardization of information. The existence of a local data library offering consistent information can reduce the extensive analysis efforts that are sometimes required to determine if differences in conclusions are a result of erroneous or inconsistent information rather than errors in method. Along with the benefits derived from high quality information, clients are able to retrieve timely information without the need to devote themselves to extensive information gathering and validation activities. In addition to the information consistency benefits, considerable savings can accrue to clients of the services as a result of the access to knowledgeable individuals whose primary business function is information management, maintenance and validation.

Other monetary benefits can accrue from bundling individual data acquisitions into larger bulk purchases. The bulk purchase benefits can also have a positive effect on the strength and depth of the relationship between the purchaser and supplier of information. For example, the Greater Vancouver Regional District has purchased the Area Master File and Postal Code Conversion File from Statistics Canada with the explicit contract recognition of the right to distribute portions of these products to member communities of the region without additional cost. Additionally, if one community has a requirement for a particular set of information, it is likely that several other communities throughout the region will be able to use the same information immediately or at some time in the future.

There are some costs associated with a service of this type. Many of the costs are attributable to increased network administration and communications services. The increased level of remote access to the systems imposes a requirement for increased awareness of system security issues. While it may appear that there could be higher costs due to increased data storage requirements, this is not actually the case, since most of the information available to the service clients is provided on top of an already substantial internal use of the information.

The primary conclusion to be drawn from the experience of the Greater Vancouver Regional District is that the Information Supermarket provides a consistent and cost effective regional perspective on planning and transportation related information to the communities of Greater Vancouver.

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A Team Approach to Distributed GIS Management

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Abstract

The City of Bellevue is developing a distributed GIS that encompasses all City departments. This presentation will cover the philosophy that led to a distributed GIS, from the organizational perspective of a team approach to GIS development. Bellevue's GIS design, management approach, teambuilding, user application development and data standards will be addressed.

The Bellevue GIS database has been in development for ten years. In the last year, with the advent of high-speed, low-cost workstations, it has become possible to distribute GIS applications, while maintaining a centralized base layer. Access among workstations is also possible, with security that provides read-only access for any layer. The philosophy behind this approach is designed to allow departmental control over specific layers of the data base, with user experts in each department trained in the use of the GIS software. In this way, the departments which already have a stake in the reliability and contents of the data are responsible for the maintenance.

The organizational issues in distributed GIS development are more important and far more challenging than the technical issues. A distributed GIS becomes a true corporate resource that requires a strong team approach to management and development. The system cannot function technically without the organizational design firmly in place. The system is maintained and managed through the processes by which the GIS is managed and new applications are designed. Needs statements for new applications are defined by user departments and then reviewed by a City-wide GIS management team. The GIS division works with the departments to set out the functional specifications, design the application and provide the training. Maintenance of the new data is the responsibility of the user department. Because all projects are created with the guidance and support of the GIS division, standards are maintained across the GIS and compatibility with existing data is ensured. GIS development is recognized as a team responsibility to provide products and services to the entire City. The partnership in the system extends to the budget process, where team support for the system has provided the constant financial support for healthy growth.